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THE EMPIRE JOURNAL OF EXPERIMENTAL AGRICULTURE

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FURTHER EXPERIMENTS ON THE INTERRELATION OF FACTORS CONTROLLING THE PRODUCTION OF COTTON UNDER IRRIGATION IN THE SUDAN

Pt. II. RESULTS AND CONCLUSIONS

A. R. LAMBERT and FRANK CROWTHER

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THE results of the experiments outlined earlier in Part I (this *J.*, 1935, **3**, 276) adequately confirm several of the conclusions based on the results of the four-factor experiments which preceded them, and the remaining conclusions from the latter experiments, based on the three factors common to all experiments, have not been refuted. There are also indications that these remaining conclusions would have been confirmed had damage by disease not modified the relative treatment-differences and also increased variation between plots of the same treatment.

The effects of diseases and pests on growth and yield are complex and varied. The Wad Husein experiment, despite the heaviest damage from Blackarm and American boll-worm, produced the greatest yields of all the experiments. It was evident from investigations on this experiment that interaction-effects between various types of plant-damage were frequent and extensive. Thus Blackarm destroyed much of the early growth of leaves, branches, and early fruits: heavy shedding of early fruits also occurred as a result of American boll-worm. The combined effect of the simultaneous leaf and early-fruit shedding was to allow the plant to resume extensive vegetative growth late in the season at a time when normally the growth would be terminated by *internal limitation due to boll-development*. The later growth was produced after the phase of pest-damage had ended, and resulted in a large, but late-maturing, final crop; this late crop is possible in the Sudan Gezira, as there is no early curtailment of the picking-season by Pink Boll-worm, such as occurs in Egypt.

The effects of damage by Blackarm may be important in relation to manurial response. Following a nitrogenous manuring, the leaves show a maximum response at a definite interval after the application; this response may be one of increase in leaf-size or number, or of increase in internal nitrogen-concentration. Where manures are applied before sowing, as in the out-station series of experiments, the maximum response usually coincides with the greatest Blackarm damage, and therefore considerable reduction in manurial response may be shown in the final crop. Thus Blackarm may be partly responsible for the smaller response to manuring with early-sown cotton in the out-station series, as compared with the corresponding response recorded in the four-factor experiments, in which manures were applied from 1 to 2 months after sowing.

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The effects of Thrips-damage on the various treatments may differ considerably from the effects of Blackarm, although in both cases premature leaf-destruction is the dominant feature. Thrips-infestation occurs later in the season than Blackarm, and consequently affects the crop at a later stage of growth. This also may be important in relation to manurial response, since some additional growth, resulting from the manuring, will have occurred before the onset of Thrips. Therefore it is improbable that Thrips will appreciably reduce the response to manuring. Thrips-infestation varies markedly with the spacing of the crop, being much more extensive on widely, than on closely, spaced plants. This again contrasts with the nature of the Blackarm damage, for, as already mentioned, this damage is usually more severe on closer, than on wider, spacings.

Summarizing the effects of Blackarm and Thrips on the interaction of manuring and spacing with sowing-date, it appears that Blackarm may reduce the manurial response and the value of close spacings with early sowings, without having any appreciable effect on later sowings, whereas Thrips damage is usually confined to later sowings and, whilst not interfering appreciably with the response to manuring, it still further emphasizes the superiority of close spacing.

Unlike the other main pests, Blackarm and Thrips, which destroy or damage the plants, Leaf-curl apparently only causes distortion of the plant-organs. No reliable measure of the effects of Leaf-curl on yield has yet been made on a field scale, since the severity of Leaf-curl infection is correlated with the vigour of the crop, the more vigorous growth being associated with greater infection [1]. Although no accurate measurement can be made of loss in crop from the disease, counts of numbers of plants infected are some guide in estimating the depressing effect of the disease. As infection only becomes appreciable from October onwards, it follows that the extent of damage by Leaf-curl is greatest on late sowings, since they are affected at an earlier stage of growth. Moreover, manured plots and wide spacings are more affected than non-manured and close spacings, since growth continues later in the former treatments.

Counts of numbers of plants infected in the out-station experiments in the 1932–3 season, when Leaf-curl was general, showed differences between the different stations, as well as well-marked differences within any one station. Yet, when corresponding yields were examined, no differential effects of the same character were evident. In this connexion it is of interest to compare the yields for the 1932–3 season, when Leaf-curl was general, with the corresponding yields in 1933–4, when Leaf-curl was comparatively negligible. In no case is it possible to ascribe any differences between the two seasons in the nature of the interactions of the treatments to the different degrees of Leaf-curl infection.

The 'Wilt' at the Ganneb Station occurring in early November 1932–3 had a differential incidence on the treatments of the late sowings. An average of 11 per cent. of the plants was either killed or severely affected, whilst the two earlier sowings had only negligible losses. The wide-spacing and manured treatments of the sowing had approximately

double the losses of the close-spacing and non-manured treatments. The reasons for these differential effects are as yet unknown.

In respect of the four pests referred to above, it will be noted that three of these—Thrips, Leaf-curl, and Wilt—tend to have the greatest incidence on the September sowing; also on the wide spacing and, to a less degree, on manured treatments of this sowing. These cumulative effects accentuate the differences in yields between the late and earlier sowings, and, more particularly, depress the yield of the wide spacing and reduce the effects of manuring for late sowing. The middle sowing, on the other hand, which is nearest to the optimum, had the lightest pest-incidence of any sowing tested.

An interaction between spacing and sowing-date, where close spacings are particularly advantageous with later sowings, appears to be general throughout the Gezira Scheme in all seasons. The existence of such an interaction might be anticipated were there a short growing-season, for the additional plants with close spacing make up for the shortened season due to later sowing. Since the picking season in the Gezira Scheme can extend over four months, it appears that there should be sufficient time for the later sowings to mature within the picking season. In point of fact, only in the first two months are the pickings heavy, and it can only be concluded that, despite the length of the total period when the cotton crop is in the ground, the effective growing-period is restricted to the earlier months, and the delay consequent upon sowing in September, instead of in early August, represents a serious curtailment of the period of favourable conditions for rapid early growth. The results show that September-sown plants are unable to compensate by greater individual plant-growth for the greater volume of soil available per plant with wider spacing. Hence, whereas a range of spacings, producing different numbers of plants per unit area, may with mid-August sowings give similar yields, with September sowings the yields increase with increase in numbers of plants per unit area, whether they are arranged in closer-spaced holes or as more plants per hole. Developmental data show that, throughout the main growing-period, the later (i.e. September) sowings have a higher leaf-to-stem ratio than the earlier sowings. This is due to restricted branch-development with later sowings. This restriction destroys the principal compensating mechanism of the plant for utilizing wider spacing, and establishes the importance of plant-number with the restricted branching of later sowings. It was suggested, in discussing the four-factor experiments, that early sowings were limited by nitrogen-supply, and that later sowings were controlled by an aerial factor, i.e. the high temperatures experienced in their early stages of growth. It is possible, therefore, that the temperatures are indirectly responsible for the reduced branch-development; this will be discussed in a subsequent paper.

It is apparent that the optimum sowing-date varies in different seasons; it was earlier in season 1933–4 than in season 1932–3. Associated with this variation in optimum is a change in the extent to which the earlier sowings compensate for wider spacing. In the four-factor experiments of the 1929–30 and 1930–1 seasons the compensation was almost complete.

In the 1933–4 season, on the other hand, in all experiments except Wad Husein, the superiority of close spacing was pronounced at all dates of sowing. It would appear to be a natural extension of the hypothesis that high temperatures limit early growth to suggest that the varying degrees of compensation possible with wider spacings are controlled by corresponding local and seasonal variations in temperature.

The large seasonal variations of yields of all treatments, indicated by the present series of experiments, together with the two four-factor experiments already described, have evoked considerable discussion, particularly as similar extensive annual fluctuations occur in the Gezira yields as a whole. It is evident that disease plays an important role in determining these yields and, whilst disease-damage remains general, it is difficult to establish the precise nature of any physiological determination which may operate in addition to disease.

That the rainfall in May and June exerts a depressing effect on yields of cotton sown in the following July or August was established by E. M. Crowther [2] on yield figures alone. Recently some confirmation has been given of this relationship by the result of a small experiment in which screening the land from early rainfall resulted in an increased yield. Hewison [3] has shown that greater annual rainfall is associated with lower yields, and vice versa. The rains later in the season also exert varying influences on yield that include the more obvious effects, such as the growth check at Hag Abdullah, due to standing water following heavy rain, and the spread of Blackarm by October rain-showers. It must be admitted that the less obvious effects of the main and late rains, together with those due to the early rains, have not so far been adequately explained. Greene [4] suggests that the optimum sowing-date is determined by the distribution of the rainfall in any season, the optimum being early in the seasons of early rainfall, &c., and he has experiments in progress designed to elucidate this relationship.

Other suggestions include the possible interference with soil cracks by the early rainfall, either by reduced rate of drying out of the soil [5], or by direct closure of the sub-soil cracks by the early rainfall [6]. Both these suggestions assume that thorough cracking of the sub-soil is essential to obtain adequate sub-soil aeration or water-penetration.

Considering the experimental results as a whole, it is concluded that these have not only given information of value with reference to the specific aims of the experiments, but have been illuminating in other respects also.

In the first place, the experimental results obtained in the original four-factor experiments at the Research Farm have been found to apply generally to other areas in the Gezira, with, however, some modification due to varying seasonal factors and pest-incidence. It is concluded, therefore, from the foregoing that the experimental results obtained at the Research Farm, in so far as they have been tested by the out-station experiments in these two years, have had a general application already noted.

Secondly, with regard to the above-mentioned modification, the out-station experiments have made possible comparison of the development of plants under identical treatments but varying soil, meteorological en-

vironment, and pest-incidence, with the final yields which followed these varying conditions. The experimental results described in this paper have therefore emphasized the importance of keeping a record of the conditions under which the crop develops, in order to understand the causes which have produced the final yield differences.

Agricultural Value of the Results

The importance of close spacing to obtain the maximum yields with late sowings has been brought out very clearly in all the results considered. The pronounced increases in yields produced by closer spacings for such sowings are of obvious agricultural importance.

The results show clearly that in order to obtain the maximum yields possible with late sowings it is necessary to have a denser population of plants per unit area than has yet been attempted under normal cultivation. The practice of leaving two plants per 'hole' for early sowings is supported by the experimental evidence. The data presented, however, indicate strongly that late sowings require both closer spacing between 'holes', and also more than two plants per 'hole', to give the maximum yields possible. The results of the multiple-factor spacing-experiments quoted indicate, in fact, that with late sowings all thinning may be abandoned with beneficial results, even with a 25-cm. spacing between holes.

The results, too, have shown that close spacing for late sowing tends to lessen pest-damage, to which these sowings appear specially liable. It also acts as an insurance against excessive reduction in crop due to stand losses.

For earlier sowings a somewhat close spacing has generally given the highest yields; it may also prevent crop-reduction from stand losses.

The degree of response to applications of ammonium sulphate remains problematical when disease and pest-damage may be general. In the four-factor experiments a definitely maximal response was obtained with the earliest sowings, but in the out-station experiments no well-defined relationship was apparent between manurial response and date of sowing of the crop.

No conclusion can be drawn as to an optimum date of sowing, except for Hag Abdullah, in which the earliest sowing gave the maximum yield in both seasons. The probability of variation in pest-incidence in other years, however, indicates the need of caution in accepting this sowing-date as the optimum for other seasons.

No consideration has been given to any differential effects of the treatments tested on ginning out-turn and quality of the lint. These will be referred to in a later paper, and only a brief reference is made here.

In general, a tendency towards lower quality with pickings later in the season has been a regular characteristic in all seasons, only partially offset by an increase in the ginning out-turns. The cotton produced by a late sowing, therefore, owing to the greater proportion of later-picked cotton, is generally of lower average quality than for earlier sowings. Closer spacing, which increases the proportion of the crop obtained in the earlier pickings, tends to increase the proportion of the better-

quality cotton, whilst wider spacings and manure tend to produce the reverse effect, by increasing the amount obtained in late pickings.

It should be noted that these spacing and manurial effects apply more particularly to later sowings, as the quality of the cotton tends to fall more rapidly with pickings later in the season. As sowings are progressively earlier, however, spacing and manurial effects of this character are complicated by other factors, more particularly Blackarm, and may not produce results similar to those for the late sowings.

Summary of Parts I and II

Field experiments are described which were designed to test whether conclusions drawn from experiments made on the Gezira Research Farm are applicable over the large areas of cultivation included under the Gezira Irrigation Scheme.

Four experiments were undertaken in 1932–3 and five in 1933–4. In each experiment comparisons were made of sowing-dates, spacings, and nitrogenous manuring in different combinations.

The marked superiority of closer spacing of the plants with sowings made after the optimum date was established in all experiments and this confirmed the conclusions from the earlier experiments. There was also seasonal variation in the extent to which wide spacings, with earlier-sown cotton, were able to compensate for the fewer plants per unit area.

The variation in response to manuring with sowing-date was not clearly defined owing, apparently, to interference by disease-damage. Where disease-damage was light the greater response to manuring with earlier sowing, established at the Research Farm, was once more obtained.

An additional experiment, designed to augment the available information on different numbers of plants per hole and different dates of thinning, is also discussed. The experiment comprised 240 plots and, in addition to showing that good yields could be obtained with late sowings if less drastic thinning were employed, demonstrated the varying importance of date of thinning as a factor controlling yield.

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THE SOILS OF SCOTLAND

Pt. III. THE CENTRAL VALLEY AND SOUTHERN UPLANDS

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THE central or midland valley consists of a tectonic trough about 50 miles wide stretching in a north-easterly and south-westerly direction from coast to coast. It is defined sharply on the north from the Highlands and less sharply on the south from the Southern Uplands by two series of faults. Only in a general sense is it a valley, for within it there are several ranges of hills. Along the northern boundary there is a broad valley, then a line of volcanic hills, then a wide lowland stretch, and to the south of this another rather discontinuous line of hills with an ill-defined valley separating it from the Southern Uplands. These hills consist of lavas, intrusive dykes, sills, and plugs, and some of them have an altitude of 1,500–2,000 ft. (457–610 m.). In his agricultural atlas of Scotland, Wood recognizes an East-Central and a West-Central region, the former comprising a belt along the east coast.

The Southern Uplands lie between the Central Valley and the English border, and consist of a great tableland stretching across the south of Scotland—the denuded remains of an old mountain range. The relief is much gentler than in the Highland region; the hills are rounded or flattish on the tops and rarely exceed 2,000 ft. (610 m.) in height. Much of the high ground consists of moorland used for sheep-grazing. The Tweed basin and the south-western coastal belt are different from the rest of the area and in Wood's atlas these are dealt with as separate agricultural regions.

Climate.—The western part of the Central Valley has on the whole a much higher rainfall than the eastern. A belt along the east coast has a rainfall of less than 30 in. (762 mm.), whilst on the west there is a rainfall of 35–60 in. (889–1,524 mm.) and over 60 in. in places. The west is characterized by cooler and wetter summers and by less sunshine than the east. The same is true of the Southern Uplands region, and associated with this climatic difference the moors in the west are found much nearer to sea-level than in the east.

Geology.—The Central Valley consists largely of sedimentary rocks, but there are considerable areas of igneous materials—lavas, dykes, &c. The two main sedimentary formations are Carboniferous and Old Red Sandstone and, as would be expected from the range of materials found in these formations (conglomerates, marls, limestones, grits, sandstones, shales, coals, and iron-stones), they give rise to a number of widely different soils. In the Old Red Sandstone formation calcareous materials occur in the marls, and in the Carboniferous they occur in the form of limestones and limy shales.

The igneous rocks vary from highly basic to acid and form the hilly ground of the region.

There are extensive alluvial deposits in the valleys of the Rivers

Tay, Forth, and Clyde forming carse lands, and throughout the Central Valley there are tracts of peat which were more extensive in former times.

The Southern Uplands consist of highly folded sediments mainly of Ordovician and Silurian age, but on the lower ground to the south Carboniferous, Old Red, and New Red Sandstone formations are found. There are also granitic intrusions. In the Ordovician and Silurian formations, which cover most of the area, the rocks are mainly shales, hard grits, and greywackes, which are very resistant to weathering, and a group of basic and intermediate lavas. Most of the region is covered with glacial drift, but on the higher ground this is thin or absent and there are extensive tracts of hill peat.

Agriculture and forestry.—Agriculturally there is a marked difference between the eastern and western portions of the Central Valley, and this difference is due chiefly to climate. In the east the farming is predominantly arable, especially near the coast and below 600 ft. (182 m.), and in the west, where there is a higher rainfall and less sunshine, pastoral farming is the general rule.

The coastal portion of the Lothians below 500 ft. (152 m.) may be taken as an example of the most intensively farmed land in Scotland, and a typical rotation in East Lothian is (1) wheat, (2) turnips, (3) barley, (4) hay, (5) oats, (6) potatoes.

In the west, barley practically disappears and in most parts there is relatively little wheat; on the other hand, the area under permanent and rotation grass is very much greater in the west than in the east. Associated with these climatic and cropping differences the proportion of cattle, and especially dairy cattle, is greater in the west, and the great development of dairying in the west is also due to the very large population in Glasgow and the surrounding districts. The upper limit of arable farming is much higher in the east than in the west; oats are found here and there in the Lothians at an altitude of well over 1,000 ft. (305 m.) and wheat as high as 700 ft. (213 m.), but most of the wheat is grown below 500 ft. (152 m.). Early potatoes are grown chiefly in the south-west coastal districts and to a less extent in the coastal belt of the Lothians—usually on raised beaches. There is a good deal of market-gardening, especially in the Clyde Valley and the Lothians, and in one or two districts (especially Blairgowrie) raspberry-growing is important.

The percentage of the total area which is under timber is much lower in this region than in the north-eastern region, and the proportion of hardwoods compared with conifers is higher—particularly in Midlothian and West Lothian. Much of the land which was originally under forest has been cleared for agricultural purposes, and destruction of the forests occurred in the past through wars and fires. A great deal of timber was used for iron-smelting and other industrial purposes, with the result that in the sixteenth century the southern part of Scotland was largely denuded of its forest, and much of the present woodland has been planted for amenity reasons.

In the Southern Uplands the higher ground is moorland, used for sheep-grazing, and the density of sheep is much lower in the west than

in the drier east. On the lower ground, e.g. the Tweed Valley, there is arable farming, but most of the region is essentially sheep-grazing land. Probably much of this area was at one time well wooded but, as in the Central Valley, great destruction of the forest occurred in the past.

Soils.—The soils of the Central Valley have been studied by various workers. The reaction, exchangeable calcium, and 'lime-requirement' of soils in the south-east were investigated by Ogg and Dow,[1] and the exchangeable bases by Smith.[2] It was found that the majority of the cultivated soils examined had a pH between 5 and 6·5, but the soils in areas where the underlying rock was Carboniferous limestone were less acid and in many cases were alkaline. A detailed acidity survey of two parishes in the east of Scotland was carried out by Ogg and Dow,[3] and in the west of Scotland by Louden.[4] Marked differences were found and the need for liming in certain areas was emphasized.

In a number of soils Smith and I. M. Robertson[5] studied the influence of the plant upon seasonal changes in soil acidity, and Smith and A. Robertson[6] investigated the effect of lime and sulphur on soil acidity, crop yield, and the absorption of calcium and sulphur by the plant.

The availability of the potassium in a group of soils from the south-east of Scotland was studied by various methods by R. Stewart.[7] Ultimate analyses showed that most of the soils contained large reserves of potash, but from Neubauer seedling-analyses he concluded that there was a deficiency of available potash in most of the samples. Smith and Coull,[8] and Smith and Dryburgh[9] studied the technique of the *Aspergillus niger* method of estimating soil fertility, and applied the method to soils of the south-east of Scotland.

On the bacteriological side, studies have been carried out by Cunningham, Gibson, Khalil, and Selim. Cunningham and Jenkins[10] worked on *Bacillus amylobacter* with special reference to its life-cycle, and Cunningham[11] carried out experiments on the cultivation of lucerne in which he refers to soil conditions. Gibson studied the decomposition of urea[12] in a number of Scottish soils, and also investigated strains of the *Bacillus pasteuri* group,[13] isolated from soils and manures. Khalil[14] studied the effect of drying on the microbiological processes in soils, and Selim[15] carried out work on nitrogen-fixing bacteria. Extensive studies of the geology and mineralogy of soils in the south of Scotland have been made by Hart.[16] The mineral composition of typical soils has been described and the content of the fine-sand fractions discussed in detail. The soils were selected over the different geological formations of the area and were shown to possess a fairly high content of silicate

[1] *J. Agric. Sci.*, 1928, **18**, 131.
[2] Ibid. 1925, **15**, 466; 1928, **18**, 68.
[3] *Scot. J. Agric.*, 1928, **11**, 273.
[4] Ibid. 1929, **12**, 383.
[5] *J. Agric. Sci.*, 1931, **21**, 822.
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[11] *Scot. J. Agric.*, 1928, **11**, 42.
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[13] *J. Bact.*, 1934, **28**, 295; 1934, **28**, 313.
[14] *Zentralbl. Bakt.*, 1929, **79**, 93.
[15] Ibid. 1931, **83**, 311.
[16] *J. Agric. Sci.*, 1929, **19**, 90; 1929, **19**, 802.

materials, generally in a comparatively fresh state. The proportion of such minerals was highest in soils derived from igneous rocks and least in those found on sediments of Carboniferous age. Minerals bearing lime, potash, and phosphate were found to be present in variable amount, though the last-named were only noted infrequently. The soils can be grouped according to their mineral content—this grouping being found to depend on the geological history of the parent material. All the soils examined were formed on glacial drifts, and the results suggest that the local rocks have a preponderating influence on the composition of the matrix of the drift.

Preliminary field studies of soils on a geological basis were carried out by Monie,[1] who has also investigated draining problems in the Central Valley. An account of the soils of North Ayrshire has been published by the Staff of the Chemistry Department of the West of Scotland College of Agriculture,[2] and soil-texture maps of North and South Ayrshire have been prepared. The mechanical composition of the layers of a group of profiles in the east of Scotland was studied by Gracie.[3]

The five main soil groups found in the north-eastern region occur also in the Central Valley and Southern Uplands, but in the Central Valley there appears to be a higher proportion of brown soils than in other regions of Scotland. Many of the cultivated soils are on the border-line between slightly podsolized soils and brown soils, and some of these are probably podsolized soils altered by agricultural treatment; calcareous parent-materials are more common in the Central Valley than in the other regions.

In the Southern Uplands the Silurian and Ordovician formations are associated chiefly with podsolic, gley podsolic, gley and peat types.

(i) *Podsolic soils.*—Examples of podsolic soils are given from three localities in the Central Valley and one in the Southern Uplands.

1 (*a*). Podsolic soil over Lower Old Red Sandstone formation.

Profile 1 (Central Valley).

Location: Balmakewan, Marykirk, Angus.
Parent material: Boulder clay over Lower Old Red Sandstone formation.
Topography and elevation: Flat; 130 ft. (40 m.).
Rainfall and drainage: 30 in. (762 mm.); fairly good.
Vegetation: Old pine forest.

(1)	0–4 cm.	Litter of needles, leaves, &c.
(2)	4–5 cm.	Dark brown humus layer; roots abundant; greyish specks at bottom of layer.
(3)	5–8 cm.	Dark greyish-brown humus layer; spotted with white specks; roots abundant; no structure.

[1] *Scot. J. Agric.*, 1922, **5**, 126; 1923, **6**, 43; 1930, **13**, 51; 1933, **16**, 418.
[2] Memoirs of the Geol. Survey; Geology of North Ayrshire, 1929.
[3] *Proc. 1st Internat. Congress Soil Sci., Washington*, 1927, **1**, 378.

(4) 8–15 cm. Olive-grey brown silty loam; friable; small stones; speckled; roots present.

(5) 15–30 cm. Mottled ochre-yellow-brown and grey-brown silty loam; slightly more compact than (4); friable; few small stones; roots present.

(6) 30–70 cm. Reddish-brown light loam with patches of greyish-brown; compact; sandy; stones throughout; roots penetrate.

(7) 70–200 cm. Passes imperceptibly into dull brick-red layer of sandy drift; friable; few large stones; grey patches throughout from decaying sandstones.

TABLE 1. *Analyses of Podsolic Soil (over Lower Old Red Sandstone formation), Marykirk, Angus*

Layer	(1)	(3)	(4)	(5)	(6)	(7)
Depth (in cm.)	0–4	5–8	8–13	15–20	30–55	85+
pH	4·3	3·7	3·9	4·3	4·5	4·6
Loss on ignition %	90·7	85·0	11·6	8·6	2·7	1·9
Exchangeable Ca (m.eq.)	..	5·3	0·8	0·6	0·6	0·6
,, Mg ,,	..	0·1	..	..	..	..
,, H ,,	..	94·0	26·7	19·5	6·0	1·2
Clay %	..	..	8·9	10·1	5·5	3·8
Clay fraction SiO_2/R_2O_3	..	..	1·96	1·46	1·44	1·35
,, SiO_2/Fe_2O_3	..	..	12·62	8·10	5·90	5·36
,, SiO_2/Al_2O_3	..	..	2·32	1·79	1·91	1·80

Profile 2 (Central Valley).

Location: Gothens Farm, Blairgowrie, Perthshire.

Parent material: Glacial drift over Lower Old Red Sandstone formation (influenced also by Highland schists).

Topography and elevation: Flat to gentle slope; 200 ft. (61 m.).

Rainfall and drainage: About 30 in. (762 mm.); good.

Vegetation: Cultivated land (raspberries grown).

(1) 0–25 cm. Brown sandy loam; few stones; roots abundant and worm-holes common; rough crumb structure.

TABLE 2. *Analyses of Podsolic Soil (over Lower Old Red Sandstone formation), Blairgowrie, Perthshire*

Layer	(1)	(2)	(3)	(4)	(5)
Depth (in cm.)	0–25	25–45	45–60	75–90	100–120
pH	5·6	6·0	6·3	6·5	6·8
Loss on ignition %	7·1	2·6	2·5	2·4	2·2
Exchangeable Ca (m.eq.)	4·5	1·5	5·3	5·3	6·6
,, Mg ,,	0·5	0·3	1·1	1·9	2·2
,, H ,,	7·6	3·9	3·2	2·6	2·4
Clay %	9·9	4·7	14·9	20·2	19·1
Clay fraction SiO_2/R_2O_3	2·04	1·25	2·42	2·53	2·49
,, SiO_2/Fe_2O_3	9·88	3·80	10·57	10·50	9·89
,, SiO_2/Al_2O_3	2·57	1·87	3·15	3·33	3·33

(2) 25–45 cm. Lighter brown sandy loam with numerous rusty spots; somewhat cemented; dark brown to blackish concretions; streaks of surface soil; fewer roots and occasional worm-holes.

(3) 45–75 cm. Brown loam with tinges of rusty brown and grey; fairly compact; lower part of this layer heavier in texture.

(4) 75–90 cm. Reddish-brown heavy loam; few stones and slight mottling.

(5) 90 cm.+ Similar to (4) but less mottling.

1 (*b*). Podsolic soil over Lower Carboniferous formation (Central Valley).

Location: Auchincruive, Ayrshire.

Parent material: Boulder clay over Coal Measures.

Topography and elevation: Gentle slope; 130 ft. (40 m.).

Rainfall and drainage: 36 in. (914 mm.); free.

Vegetation: Wooded pasture-land; chiefly species of *Festuca*, *Agrostis*, *Holcus*, and *Lolium*.

(1) 0–30 cm. Dark brown light sandy loam; few stones; many roots to depth of 25 cm.

(2) 30–60 cm. Brown light sandy loam; grittier and more compact than (1); roots and worm-channels cease at 45 cm.

(3) 60–90 cm. Fairly sharp transition to rusty brown compacted sandy loam, showing iron staining, and free from stones.

(4) 90–95 cm. Transition layer to yellowish-brown compacted fine sandy loam.

(5) 95–110 cm. Yellowish-brown compacted sandy loam, less gritty than (4); a few rounded and sub-angular stones present.

(6) 110–120 cm. Darkish brown gritty sandy loam; very much compacted; a few rounded and sub-angular stones.

(7) 120 cm.+ Brown fine silty loam with purplish tinge; shaly material present; grey and dull orange mottling; few stones.

TABLE 3. *Analyses of Podsolic Soil (over Lower Carboniferous formation),* Auchincruive, Ayrshire*

Layer	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Depth (in cm.)	0–30	30–60	60–90	90–95	95–110	110–120	120+
pH	5·2	5·7	5·9	6·1	6·1	6·3	6·5
Loss on ignition %	7·3	4·3	3·6	4·0	3·2	2·8	4·8
Exchangeable Ca (m.eq.)	2·7	3·0	3·1	2·2	2·3	2·2	9·8
,, Mg ,,	<0·1	..	..	..	..	..	..
Clay %	10·6	7·1	4·8	7·5	6·2	5·4	20·4
Clay fraction SiO_2/R_2O_3	1·64	1·30	1·11	1·00	1·17	1·83	2·36
,, SiO_2/Fe_2O_3	6·04	4·52	3·21	2·22	2·72	7·42	9·10
,, SiO_2/Al_2O_3	2·26	1·82	1·70	1·83	2·08	2·42	3·19

* Data supplied by I. C. Jack.

1 (*c*). Podsolic soils over Silurian formation (Southern Uplands).

Profile 1.

Location: Wull Muir, Broad Law, Moorfoot Hills, Midlothian.
Parent material: Boulder clay over shale.
Topography and elevation: Gentle slope; 1,250 ft. (381 m.).
Rainfall and drainage: About 35–40 in. (889–1,016 mm.); fairly good.
Vegetation: *Eriophorum vaginatum*; *Callina vulgaris* and *Vaccinium Myrtillus* dominant; *Nardus stricta*; *Deschampsia flexuosa* and *Molinia coerulea* abundant.

(1) 0–5 cm. Mat of heather and blaeberry roots, slightly decomposed.
(2) 5–20 cm. Black peaty material; many roots and few stones; silty texture.
(3) 20–27 cm. Greyish-black peaty loam, containing much mineral material; gritty, with white specks; some fresh roots, but many decayed, with staining round them.
(4) 27–32 cm. Coffee-brown loam, colour probably due to staining with organic matter; friable and gritty; small stones throughout and no definite structure; roots present; slightly damp.
(5) 32–45 cm. Medium-brown loam, gritty and friable; slightly stony; roots present; no definite boundary between layers (4) and (5); damp.
(6) 45–80 cm. (Variable) Greyish-brown loam; gritty and friable; no definite structure; very stony and stones mostly angular; some brown staining; colour becomes more uniformly grey-brown with depth.
(7) 80 cm. + Rock rubble of broken shale with small admixture of fine material.

TABLE 4. *Analyses of Podsolic Soil (over Silurian formation), Wull Muir, Moorfoot Hills, Midlothian*
Profile 1

Layer	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Depth (in cm.)	0–5	5–20	20–27	27–32	32–45	45–80	135–150
pH	4·0	3·8	4·1	4·3	4·7	4·7	4·9
Loss on ignition %	92·3	41·0	17·5	15·4	12·0	4·5	5·9
Exchangeable Ca (m.eq.)	..	0·9	0·6	0·7	0·6	0·6	0·9
,, Mg ,,	..	0·7	0·2	0·2	0·1	0·1	0·5
,, H ,,	86·3	50·7	36·0	32·0	18·3	5·2	6·9
Clay fraction SiO_2/R_2O_3	..	..	2·80	1·81	1·21	1·65	1·60
,, SiO_2/Fe_2O_3	..	..	31·59	8·11	4·36	6·49	6·69
,, SiO_2/Al_2O_3	..	..	3·07	2·33	1·68	2·21	2·10

Profile 2.

The following is an example of a podsolic soil over Silurian shale in the same locality as the last but on a sloping gravelly bank:

Vegetation: *Agrostis canina*, *A. vulgaris*, *Festuca ovina*, *Galium*

saxatile; less abundant, *Potentilla sylvestris, Luzula campestris, Nardus stricta.*

(1) 0–6 cm. Mat of grass roots.
(2) 6–17 cm. Light chocolate-brown friable loam with many grass roots; few stones; slightly powdery when dry; ochre yellow spots; worm-holes.
(3) 17–40 cm. Bright brown friable silty loam; slightly gritty; some stones; damp; roots common; pores and worm-holes; no definite structure.
(4) 40–70 cm. Grey-brown very pebbly and gritty silty loam; cemented; much silty material amongst interstices of shale pebbles; slightly damp; brown patches; roots present.
(5) 70 cm.+ Shaly rubble, mostly angular and flat; silty interstitial material; very hard and appears to be cemented; damp; roots penetrate into this layer.

TABLE 5. *Analyses of Podsolic Soil (over Silurian formation), Wull Muir, Moorfoot Hills*
Profile 2

Layer	(1)	(2)	(3)	(4)	(5[1])	(5[2])
Depth (in cm.)	0–6	6–17	17–40	40–70	70–90	90+
pH	4·5	4·4	4·6	4·7	4·9	5·2
Loss on ignition %	52·3	16·5	11·3	7·5	4·6	4·3
Exchangeable Ca (m.eq.)	2·2	0·7	0·6	0·6	0·6	4·6
,, Mg ,,	2·6	0·8	0·6	0·4	0·6	2·3
,, H ,,	39·7	23·8	18·1	13·7	8·1	5·2
Clay fraction SiO_2/R_2O_3	..	1·91	1·67	1·56	2·03	2·38
,, SiO_2/Fe_2O_3	..	8·63	7·40	6·34	9·83	11·54
,, SiO_2/Al_2O_3	..	2·45	2·16	2·08	2·56	2·91

The above examples illustrate podsolic soils on three geological formations and under five different types of vegetation. The parent materials are light in texture, allowing free drainage, and the podsolic type is usual under these conditions. The clay-fraction analyses show translocation of sesquioxides and there are also morphological evidences of podsolization. In the Blairgowrie profile, where the texture becomes heavier with increasing depth, there is some evidence of slight gleying in the C horizon.

(ii) *Gley podsolic soils.*—Examples are given over Carboniferous and Silurian formations and also over trachyte.

2 (*a*). Gley podsolic soils over the Calciferous Sandstone Series of the Carboniferous formation (Central Valley).

Two profiles are described, one in Moffat Wood and the other in adjoining cultivated ground on the farm of Spittalrig.

Uncultivated profile.

Location: Moffat Wood, Gladsmuir, East Lothian.

Parent material: Boulder clay over the Calciferous Sandstone Series of the Lower Carboniferous.

Topography and elevation: Flat, 300 ft. (91 m.).
Rainfall and drainage: 28 in. (711 mm.); slightly impeded.
Vegetation: Chiefly pine forest.

(1) 0–5 cm. Surface litter of needles, leaves, &c.
(2) 5–10 cm. Brownish-grey silty loam; damp; structureless; roots present; stoneless; compact.
(3) 10–20 cm. Predominantly grey silty loam with brown streaks along root-channels; rusty brown spots and lighter grey flecks; minute pores; friable when dry; compact.
(4) 20–45 cm. Mottled grey and ochre-yellow silty clay; rusty brown spots around root-channels; friable; compact; stones rare; roots fairly abundant; pores; structureless.
(5) 45–90 cm. As in layer (4) but grey predominating; more stony; particles of coal and decaying sandstone.
(6) 90 cm.+ Reddish-brown slightly gritty clay with red, grey, and black specks; stones present; compact, but roots penetrate; sandy phase occurs in places.

TABLE 6. *Analyses of Gley Podsolic Soil (uncultivated) (over Lower Carboniferous formation), Moffat Wood, East Lothian*

Layer	(2)	(3^1)	(3^2)	(4)	(5)	(6)
Depth (in cm.)	5–7	10–15	15–20	20–35	50–60	100+
pH	4·0	3·9	4·0	4·3	4·5	5·4
Loss on ignition %	36·3	8·4	4·6	6·6	5·0	5·1
Exchangeable Ca (m.eq.)	4·0	0·9	0·6	1·0	1·0	6·8
„ Mg „	1·8	0·7	0·9	0·9	1·2	4·1
„ H „	41·2	19·3	11·1	10·0	7·9	3·5
Clay %	20·7	22·4	27·0	36·9	28·1	27·9
Clay fraction SiO_2/R_2O_3	2·26	2·29	2·20	1·82	1·77	2·26
„ SiO_2/Fe_2O_3	19·67	50·48	28·44	6·23	6·61	11·71
„ SiO_2/Al_2O_3	2·55	2·39	2·39	2·57	2·42	2·80

Cultivated profile at Spittalrig Farm.

(1) 0–25 cm. Dark chocolate-brown heavy loam; gritty and pebbly; rough crumb structure; cracks in very dry weather; full of roots; worm-holes; stones frequent.
(2) 25–40 cm. Ochre and grey loam; gritty; compact; structureless; stony; roots penetrate; the ochre-and-grey colour due in part to decaying yellow and white sandstone.
(3) 40–65 cm. (Variable.) Brown and grey clay; gritty, sticky, and damp; much rusty mottling; some yellow coloration due to sandstone; black particles of coal and shale; roots penetrate.
(4) 65–150 cm. Similar to above but with more intense grey patches and streaks; mottled brown and grey; stony; roots penetrate to 120 cm.

(5) 150 cm.+ Chocolate-brown boulder clay; stiff and sticky; damp; slight rusty and grey mottling at 150 cm.; stones are white, yellow, and purple sandstones, coal, shale, limestone, and basalt.

TABLE 7. *Analyses of Gley Podsolic Soil (cultivated) (over Lower Carboniferous formation), Spittalrig, East Lothian*

Layer	(1)	(2)	(3)	(4¹)	(4²)	(5)
Depth (in cm.)	0–25	25–40	40–65	65–100	100–140	150+
pH	6·2	7·2	7·0	5·4	5·3	5·3
Loss on ignition %	8·0	4·8	5·7	6·1	6·0	6·6
Exchangeable Ca (m.eq.)	10·0	6·8	7·5	5·2	3·7	4·6
,, Mg ,,	1·0	1·1	1·8	2·9	3·0	3·5
,, H ,,	0·9	0·2	0·6	2·2	3·4	2·6
Clay %	20·0	23·6	29·3	28·0	28·2	28·0
Clay fraction SiO_2/R_2O_3	1·54	1·63	1·78	1·89	2·19	2·02
,, SiO_2/Fe_2O_3	9·76	5·15	6·42	7·67	12·27	9·30
,, SiO_2/Al_2O_3	1·82	2·37	2·47	2·50	2·58	2·57

2 (*b*). Peat gley podsolic soil over Silurian formation (Southern Uplands).

Location: Wull Muir, Moorfoot Hills, Midlothian.
Parent material: Boulder clay over Silurian shale.
Topography and elevation: Fairly steep slope; 1,250 ft. (381 m.).
Rainfall and drainage: About 35–40 in. (889–1,016 mm.); impeded.
Vegetation: *Nardus stricta* dominant; *Deschampsia flexuosa*, *Molinia coerulea*, *Agrostis canina*, *Festuca ovina*, *Galium saxatile*, and *Polytrichum commune* abundant.

(1) 0–15 cm. Black amorphous peat, full of roots; coarse lumpy structure.
(2) 15–25 cm. Dark grey stony heavy loam; structureless; wet.
(3) 25–25·5 cm. Dark brown and rusty hard-pan; roots penetrate in places.
(4) 26–55 cm. Fawny-brown stony heavy loam; structureless and not very compact; roots penetrate.
(5) 55–65 cm. Greenish-brown stony layer with interstitial finer material; structureless; roots penetrate.

TABLE 8. *Analyses of Peat Gley Podsolic Soil (over Silurian formation), Wull Muir, Moorfoot Hills*

Layer	(1)	(2)	(4¹)	(4²)	(5)	(6)	(7¹)	(7²)
Depth (in cm.)	0–15	15–25	25–35	45–55	55–65	65–75	80–90	150+
pH	4·3	4·3	4·8	5·1	4·8	4·9	4·8	5·0
Loss on ignition %	79·3	16·1	10·1	6·6	5·2	7·4	4·7	3·2
Exchangeable Ca (m.eq.)	1·8	0·8	0·5	0·5	0·5	0·6	0·5	0·5
,, Mg ,,	<0·1	..	..	..	..	..	..	..
,, H ,,	56·9	29·4	16·9	8·8	6·4	7·6	7·6	4·9
Clay %	..	22·6	21·1	13·9	10·1	8·5	12·5	8·7
Clay fraction SiO_2/R_2O_3	..	2·64	1·77	1·48	1·57	1·36	1·81	1·67
,, $SiO_2Fe_2O_3$	..	32·45	7·81	5·57	6·40	5·75	10·40	8·00
,, SiO_2/Al_2O_3	..	2·87	2·29	2·01	2·07	1·77	2·19	2·11

(6) 65–75 cm. Fawny-brown loam similar to layer (5), but redder in colour and fewer roots.

(7) 75 cm.+ Brown loam with many small angular pieces of slate; greenish-grey in places; structureless; very few roots.

2 (*c*). Gley podsolic soil over trachyte (Central Valley).

Location: Smiddy park, Harperdean, Haddington.
Parent material: Boulder clay over trachyte.
Topography and elevation: Level; 500 ft. (152 m.).
Rainfall and drainage: About 25 in. (635 mm.); fairly good.
Vegetation: Pasture (in rotation).

(1) 0–25 cm. Dark brown heavy loam; powdery when dry; slightly gritty, but stones infrequent; worm-holes common; roots abundant.

(2) 25–50 cm. Yellow-brown heavy loam with greyish tint; some rusty and ochre mottling; rusty staining round root-channels; many pores; worm-channels and roots common; stones fairly frequent; lumpy indefinite structure.

(3) 50–75 cm. Brown clay loam with greyish tint; gritty and stony; rusty and grey mottling; worm-holes frequent; cloddy when broken up, and grey films on surfaces of lumps; more uniformly brown in colour with depth.

(4) 75–165 cm. Brown gritty and stony boulder clay; rusty and grey mottling; stones frequent; trachyte, basalt, yellow, and purple sandstones, coal, grits, and shale; stones generally soft and decayed.

TABLE 9. *Analyses of Gley Podsolic Soil (over trachyte), Harperdean, Haddington, West Lothian*

Layer	(1)	(2)	(3)	(4[1])	(4[2])	(4[3])
Depth (in cm.)	0–25	30–45	55–75	95–110	125–150	150–165
pH	6·6	7·4	7·8	7·2	6·5	7·4
Loss on ignition %	8·1	5·1	5·1	4·8	5·9	5·0
Exchangeable Ca (m.eq.)	11·8	11·3	12·1	13·2	10·7	22·2
,, Mg ,,	1·1	0·9	1·3	1·3	1·5	5·0
Clay %	23·9	28·5	28·8	26·2	27·0	14·2
Clay fraction SiO_2/R_2O_3	1·89	1·70	2·08	2·12	2·13	2·66
,, SiO_2/Fe_2O_3	11·62	7·72	12·11	13·51	14·58	9·72
,, SiO_2/Al_2O_3	2·27	2·19	2·52	2·52	2·49	3·66

The above examples of gley podsolic soils are taken from three different types of parent material, and occur under three types of vegetation. The parent materials are heavier in texture than those described in the podsolic group, and this no doubt accounts for the gleying. The two profiles from cultivated land show evidence of marked alteration through treatment and have probably been heavily limed in the past. The parent material in the slightly podsolized Harperdean profile is

of very mixed origin, and is evidently influenced largely by the neighbouring Carboniferous formation. This soil is on the border-line of the brown-soil group, but the analyses show fairly marked translocation of sesquioxides.

(iii) *Gley soils.*—Two examples of a gley and a peat gley are given from Wull Muir, Moorfoot Hills. The parent material in both cases is boulder clay over Silurian shale; the height above sea-level is 1,250 ft. (381 m.), and the rainfall 35–40 in. (889–1,016 mm.).

Gley profile (Southern Uplands).

Vegetation: *Juncus communis* and *Carex Goodenovii* dominant; *Holcus lanatus*, *Trifolium repens*, and *Anthoxanthum odoratum* abundant.

(1) 0–5 cm. Mat of roots and moss.
(2) 5–15 cm. Brownish-grey silty loam; wet; no definite structure; few stones; roots common; some brown patches along root-channels.
(3) 15–22 cm. (Variable.) Grey silty loam with brown patches and streaks; wet; few stones; roots common; brown staining along root-channels.
(4) 22–35 cm. Brown silty loam with greyish tinge; wet; slightly gritty; few stones; much brown mottling and staining along root-channels.
(5) 35–55 cm. Greyish-brown silty loam with sandy patches; wet; stones common; blackish particles or concretions; roots penetrate; brown staining along root-channels.
(6) 55 cm.+ Stony silty loam; grey-brown with brown patches; very wet; gritty.

TABLE 10. *Analyses of Gley Soil (over Silurian shale), Wull Muir, Moorfoot Hills*

Layer	(1)	(2)	(3)	(4)	(5)	(6)
Depth (in cm.)	0–5	5–15	15–22	22–35	35–55	55+
pH	5·2	5·3	5·6	5·4	5·8	5·5
Loss on ignition %	18·4	12·6	7·3	5·2	4·1	3·6
Exchangeable Ca (m.eq.)	5·3	3·7	4·1	4·0	3·5	1·8
,, Mg ,,	2·0	1·4	1·3	1·4	1·6	0·7
,, H ,,	14·6	12·5	9·0	6·5	6·0	4·8
Clay fraction SiO_2/R_2O_3	2·44	2·32	2·37	2·28	2·12	1·82
,, SiO_2/Fe_2O_3	14·11	12·45	11·50	10·74	9·71	8·72
,, SiO_2/Al_2O_3	2·96	2·85	2·98	2·89	2·71	2·29

Peat Gley profile (Southern Uplands).

Vegetation: *Eriophorum vaginatum*, *Carex Goodenovii*, *Deschampsia flexuosa*, and *Festuca ovina*; spots of *Calluna vulgaris*.

(1) 0–4 cm. Mat of roots.
(2) 4–30 cm. Fibrous peaty material; roots abundant.
(3) 30–37 cm. Greyish silty loam with much organic staining; many plant roots with brown staining around them; most of roots decayed.

(4) 37–50 cm. Grey fine sandy loam; damp; many roots; some green patches; brown staining, especially along root-channels.

(5) 50–65 cm. Greenish-grey silt; gritty and slightly stony; damp; roots common—some decayed, with brown patches along channels.

(6) 65–95 cm. Greyish-brown gritty and stony silty loam; many greyish-green patches; becomes more uniform in colour with increasing depth; damp; roots penetrate only to top of layer.

(7) 95 cm.+ Brown gritty and stony loam; clayey; wet; very stony—shattered shale; greyish-green patches, probably due to decayed shale.

TABLE 11. *Analyses of Peat Gley Soil (over Silurian shale), Wull Muir, Moorfoot Hills*

Layer	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Depth (in cm.)	0–4	4–30	30–37	37–50	50–65	65–95	150–165
pH	4·3	3·9	4·7	5·1	5·0	6·0	6·7
Loss on ignition %	91·0	70·2	9·4	1·2	3·2	3·7	4·0
Exchangeable Ca (m.eq.)	..	5·9	2·1	1·2	3·7	9·2	13·5
,, Mg ,,	..	2·9	1·3	0·8	2·1	4·1	4·6
,, H ,,	27·8	49·1	12·3	1·2	2·3	0·6	0·3
Clay fraction SiO_2/R_2O_3	..	..	2·44	2·35	2·38	2·41	2·31
,, SiO_2/Fe_2O_3	..	..	21·28	14·55	12·66	11·49	9·88
,, SiO_2/Al_2O_3	..	..	2·75	2·80	2·94	3·05	3·01

Both profiles described are from the Southern Uplands at a fairly high altitude. Compared with the podsolic and gley podsolic soils, already described from the same locality, they show a rather higher pH and a higher content of exchangeable calcium and magnesium. The SiO_2/Fe_2O_3 decreases in both profiles with increasing depth.

(iv) *Brown soils.*—In Part II of this paper, brown soils over gabbro were described. In the Central Valley and Southern Uplands, examples over dolerite and the Carboniferous and Old Red Sandstone formations are given.

4 (*a*). Brown soils over Lower Old Red Sandstone formation.

Profile 1 (Central Valley).

Location: Bent, Laurencekirk, Kincardineshire.

Parent material: Boulder clay over Lower Old Red Sandstone formation.

Topography and elevation: Flat to gently rolling; 230 ft. (70 m.).

Rainfall and drainage: 33 in. (838 mm.); good.

Vegetation: Cultivated ground.

(1) 0–25 cm. Greyish-brown gritty heavy loam; stony; when dry becomes lighter in colour and crumbly; worms present.

(2) 25–125 cm. Reddish-brown stony heavy loam; small soft black specks; occasional patches bright red in colour; fairly compact; few roots below 45 cm.

TABLE 12. *Analyses of Brown Soil (over Lower Old Red Sandstone formation), Laurencekirk, Kincardineshire*

Layer	(1¹)	(1²)	(2¹)	(2²)	(2³)	(2⁴)
Depth (in cm.)	0–12	12–25	25–35	35–45	65–75	115–25
pH	6·3	6·4	5·8	5·4	5·6	5·9
Loss on ignition %	6·2	6·5	3·9	3·2	2·8	3·2
Exchangeable Ca (m.eq.)	10·6	9·9	6·3	5·5	6·0	8·4
,, Mg ,,	2·0	1·5	2·0	2·9	4·2	4·2
,, H ,,	1·8	2·8	2·8	2·1	2·1	1·4
Clay %	18·9	19·5	20·4	20·5	20·2	21·8
Clay fraction SiO_2/R_2O_3	2·68	2·68	2·83	2·49	2·64	2·74
,, SiO_2/Fe_2O_3	13·76	15·99	15·15	13·45	13·79	14·17
,, SiO_2/Al_2O_3	3·32	3·22	3·48	3·05	3·27	3·40

Profile 2 (Central Valley).

Location: Balfeith, Fordoun, Kincardineshire.

Parent material: Boulder clay over marls of Lower Old Red Sandstone formation.

Topography and elevation: Level; 200 ft. (61 m.).

Rainfall and drainage: 33 in. (838 mm.); fairly good.

Vegetation: Pasture (in rotation).

(1) 0–25 cm. Light reddish-brown heavy loam; many roots; occasional stones; tendency to crumb structure.

(2) 25–35 cm. Reddish-brown stony heavy loam; few roots; structureless.

(3) 35–80 cm. Bright reddish-brown stony loam; compact; no roots; structureless.

(4) 80–90 cm. Reddish-brown rotten marl with some fine material in cracks.

(5) 90–100 cm. Rotten rock with less fine material than (4); wet.

TABLE 13. *Analyses of Brown Soil (over Lower Old Red Sandstone marl), Fordoun, Kincardineshire*

Layer	(1¹)	(1²)	(2)	(3¹)	(3²)	(4)
Depth (in cm.)	0–12	12–25	25–35	45–55	70–80	80–90
pH	6·3	6·7	6·9	7·2	7·1	7·1
Loss on ignition %	7·0	6·0	3·8	3·4	3·8	4·0
Exchangeable Ca (m.eq.)	12·5	14·2	12·8	12·9	11·7	11·6
,, Mg ,,	2·5	3·0	3·6	4·8	4·5	4·9
,, H ,,	5·3	1·9	1·6	2·0	0·4	2·2
Clay %	24·3	23·6	18·2	16·4	17·9	17·9
Clay fraction SiO_2/R_2O_3	2·81	2·69	3·03	2·85	3·03	3·05
,, SiO_2/Fe_2O_3	13·14	11·09	15·95	12·68	20·50	16·58
,, SiO_2/Al_2O_3	3·58	3·53	3·74	3·77	3·55	3·73

Profile 3 (Southern Uplands).

Location: Wallace Field, Bemersyde West End, Bemersyde, Berwickshire.
Parent material: Boulder clay over sandstone of Old Red Sandstone formation.
Topography and elevation: Gentle slope; 500 ft. (152 m.).
Rainfall and drainage: About 28 in. (711 mm.), free.
Vegetation: Grass (in rotation).

(1) 0–20 cm. Brownish-red heavy loam; comparatively free of stones.
(2) 20–35 cm. Similar to above, but very stony.
(3) 35–47 cm. Brownish-red loam but lighter in colour than (1); stony.
(4) 47–65 cm. Redder in colour than (3); texture similar; roots still present.
(5) 65–100 cm. Reddish stony loam similar to layers (3) and (4); worms present.
(6) 100–35 cm. Reddish loam similar in texture to above but deeper in colour.
(7) 135 cm.+ Shattered sandstone rock at variable depth.

TABLE 14. *Analyses of Brown Soil (over Old Red Sandstone formation), Bemersyde, Berwickshire*

Layer	(1)	(2)	(3)	(4)	(5)	(6)
Depth (in cm.)	0–20	25–35	37–47	55–65	80–100	115–135
pH	5·9	6·2	6·1	6·2	6·0	5·3
Loss on ignition %	5·4	3·8	3·6	2·9	2·7	2·9
Exchangeable Ca (m.eq.)	7·7	5·3	5·6	3·6	4·8	2·6
,, Mg ,,	1·0	0·6	0·8	0·7	1·3	1·7
,, H ,,	2·0	0·9	0·5	1·4	1·2	1·2
Clay %	20·5	19·0	19·9	17·9	18·8	21·7
Clay fraction SiO_2/R_2O_3	2·34	2·34	2·45	2·38	2·52	2·64
,, SiO_2/Fe_2O_3	12·82	11·54	12·51	9·01	10·63	9·32
,, SiO_2/Al_2O_3	2·87	2·94	3·02	3·24	3·31	3·35

4 (*b*). Brown soils over Carboniferous formation (Central Valley).

Profile 1.

Location: Clack O' Ford field, Oxwell Mains, Dunbar, East Lothian.
Parent material: Glacial drift over Carboniferous Limestone Series (influenced by adjoining Old Red Sandstone formation).
Topography and elevation: Level; 80 ft. (24 m.).
Rainfall and drainage: 24 in. (610 mm.), good.
Vegetation: Under cultivation.

(1) 0–30 cm. Reddish-brown stony loam; free and friable; soft crumb structure.
(2) 30–110 cm. Reddish-brown very stony loam; loose and structureless; roots penetrate to 100 cm.

TABLE 15. *Analyses of Brown Soil (over Carboniferous formation), Dunbar, East Lothian*

Layer	(1^1)	(1^2)	(2^1)	(2^2)	(2^3)
Depth (in cm.)	0–15	15–30	30–45	45–60	100+
pH	7·6	7·3	7·6	7·5	7·1
Loss on ignition %	6·2	4·8	3·8	3·7	3·4
Exchangeable Ca (m.eq.)	23·1	20·4	12·3	7·9	8·1
,, Mg ,,	1·9	2·0	1·3	0·7	0·8
Clay %	16·7	17·0	16·7	11·9	12·2
Clay fraction SiO_2/R_2O_3	2·05	2·01	2·03	2·04	1·96
,, SiO_2/Fe_2O_3	8·88	9·17	8·62	8·26	6·97
,, SiO_2/Al_2O_3	2·68	2·58	2·66	2·72	2·56

Profile 2 (Central Valley).

Location: Fox farm field, East Saltoun, East Lothian.
Parent material: Boulder clay over Carboniferous Limestone Series.
Topography and elevation: Level; 500 ft. (152 m.).
Rainfall and drainage: About 28 in. (711 mm.); fair.
Vegetation: Pasture (in rotation).

(1) 0–35 cm. Brown heavy loam; few stones; becomes slightly lighter in colour below 25 cm.
(2) 35–50 cm. Grey and yellow clay loam; compact; stones present.
(3) 50–110 cm. (Variable.) Grey, red, and orange mottled sandy clay; very compact; stones present; roots and worms in upper part of this layer.
(4) 110–130 cm. Yellow and red sandy clay overlying rock at about 150 cm.

TABLE 16. *Analyses of Brown Soil (over Carboniferous Limestone Series), East Saltoun, East Lothian*

Layer	(1^1)	(1^2)	(2)	(3^1)	(3^2)	(4)
Depth (in cm.)	0–23	25–35	40–50	55–70	75–95	115–130
pH	7·8	7·7	7·6	7·7	7·3	7·9
Loss on ignition %	8·5	7·1	6·7	7·2	7·0	12·8
Clay %	22·3	28·1	35·2	43·0	39·8	41·1
Clay fraction SiO_2/R_2O_3	1·98	1·88	1·81	1·80	2·00	1·56
,, SiO_2/Fe_2O_3	18·35	16·73	17·11	17·34	25·50	26·25
,, SiO_2/Al_2O_3	2·22	2·12	2·02	2·01	2·17	2·08

4 (*c*). Brown soil over dolerite (Central Valley).

Location: Peel Hill, Auchincruive, Ayrshire.
Parent material: Boulder clay over teschenitic dolerite sills.
Topography and elevation: Gentle slope; 100 ft. (30 m.).
Rainfall and drainage: About 36 in. (914 mm.); good.
Vegetation: Old pasture formerly cultivated; species of *Agrostis*, *Festuca*, and mosses dominant.

(1) 0–10 cm. Darkish chocolate-brown light loam; surface mat of grass and roots; free from stones.

(2) 10–27 cm. Light loam; lighter in colour than (1); gravel and small angular and rounded stones; roots not abundant below this layer.

(3) 27–35 cm. Similar to (2) but few roots; somewhat compacted.

(4) 35–45 cm. Light-brown sandy loam; some reddish-brown and black staining; compacted and free from stones and gravel; no trace of worms below this layer.

(5) 45–85 cm. Dark purplish-brown compact boulder clay; considerable admixture of shaly material; angular, sub-angular, and rounded stones present; irregular columnar structure in layers (2) to (5); roots stop at 55 cm.

TABLE 17. *Analyses of Brown Soil (over Dolerite),* Peel Hill, Auchincruive, Ayrshire*

Layer	(1)	(2)	(3)	(4)	(5)
Depth (in cm.)	0–10	10–27	27–35	35–45	45–85
pH	5·6	5·7	6·6	6·6	7·4
Loss on ignition %	10·5	6·6	3·9	3·0	4·0
Exchangeable Ca (m.eq.)	4·5	4·7	6·0	4·5	6·4
,, Mg ,,	<0·1	..	..	..	..
Clay %	12·6	12·1	14·7	6·0	11·0
Clay fraction SiO_2/R_2O_3	1·96	2·00	2·10	2·01	2·30
,, SiO_2/Fe_2O_3	6·70	7·21	7·55	8·70	8·84
,, SiO_2/Al_2O_3	2·77	2·69	2·90	2·70	3·10

* Data supplied by I. C. Jack.

As in the north-eastern region, the brown soils appear to be typically associated with parent material from basic rocks. The two profiles with the lowest pH in the parent material (Bent and Bemersyde) show evidence of having been limed in the past, and that from Bemersyde may be a regraded podsol. Translocation of sesquioxides, where it occurs, is slight and morphologically there is no evidence of podsolization. The analytical data for the Oxwell Mains, Harperdean, and East Saltoun profiles were supplied by R. L. Mitchell.

(v) *Soil with undeveloped profile* (Southern Uplands).

Location: Wull Muir, Moorfoot Hills.
Parent material: Drift over Silurian shale.
Topography and elevation: Slope, 1,250 ft. (381 m.).
Rainfall and drainage: About 35–40 in. (889–1,016 mm.); fairly good.
Vegetation: *Agrostis vulgaris*, *A. canina*, and *Festuca ovina* dominant; *Deschampsia caespitosa* abundant.

(1) 0–30 cm. Greyish-brown crumbly loam with thick root-mat on surface; occasional worms; stony; moist.

(2) 30–60 cm. Fawny-brown loam; gritty and sticky; few roots; stony; spots of lighter coloured material; greenish rotten rock; no roots below 60 cm.

(3) 60 cm.+ Fawny-brown loam; gritty and very stony; rusty brown spots; moist.

TABLE 18. *Analyses of Soil with undeveloped Profile (over Silurian shale), Moorfoot Hills*

Layer	(1^1)	(1^2)	(2^1)	(2^2)	(3^1)	(3^2)
Depth (in cm.)	0–10	10–20	30–40	50–60	60–70	150+
pH	5·2	5·6	5·9	6·1	6·2	6·1
Loss on ignition %	13·2	11·1	7·1	6·1	4·1	3·7
Exchangeable Ca (m.eq.)	4·7	5·6	5·6	5·3	4·9	7·0
,, Mg ,,	2·0	1·9	1·9	1·6	1·7	2·3
,, H ,,	15·0	11·7	8·5	8·0	5·3	4·1
Clay fraction SiO_2/R_2O_3	2·36	2·34	2·18	2·14	2·06	2·16
,, SiO_2/Fe_2O_3	11·87	11·81	10·10	9·82	8·88	10·07
,, SiO_2/Al_2O_3	2·95	2·92	2·77	2·73	2·68	2·76

The undeveloped state of the above profile is probably mainly due to percolation of water down the slope within the profile and partly to downwash of material. The pH and the contents of exchangeable calcium and magnesium are much higher than in the podsolic soils from the same locality.

Summary

A review has been given of previous soil investigations in Scotland. Typical soil profiles from various parts of the country have been described, and examples given from a wide range of parent materials. Determinations have been made of pH, loss on ignition, exchangeable calcium, magnesium and hydrogen, percentage of clay, and composition of the clay fractions.

The following broad groups are recognized: podsolic soils, gley podsolic soils, gley soils and deep peat, brown soils, and soils with undeveloped profiles. Further subdivisions are made on a geological basis.

Most of the Scottish soils examined come within the podsolic and gley podsolic groups; a peat-covering is common, especially in the Highlands and Hebrides. Brown soils which appear to be similar to the 'brown earths' of certain continental workers are not uncommon in the Central Valley and in parts of the north-eastern region.

Marked changes have been brought about in many soils through cultivation and treatment, and some of these cultivated soils, although originally podsolic, now resemble the brown soils.

Lysimeter experiments on a granitic drift soil in Aberdeenshire have been described, and a brief account given of fertility investigations and mineralogical studies.

I desire to acknowledge the valuable assistance I have received from Mr. H. G. M. Hardie, and also to thank various other members of the staff of the Macaulay Institute—in particular Dr. Hart and Dr. Muir—for much helpful criticism.

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THE EFFECTS OF VARYING AMOUNTS OF ANIMAL PROTEIN FED TO WHITE LEGHORN PULLETS

Pt. II. FACTORS CORRELATED WITH EGG-SIZE AND NUMBER OF EGGS

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THE data of the experiment presented in Part I of this paper (this *Journal*, 1935, **3**, 215) provided an excellent opportunity to gather further evidence of the correlation between various characteristics of a pullet and the eggs she lays. The results have been obtained under Western Cape Province conditions, which differ not only from conditions existing in other parts of South Africa, but also from conditions in countries where similar experiments have been performed. (The material and methods utilized in obtaining these results are detailed in Part I.)

Review of literature.—That the weight of the eggs produced by a pullet gradually increases until a maximum is reached either in the first year of production or later, has long been established.

Maximum body-weight has been found significantly correlated with average annual egg-weight by Atwood [1], Atwood and Clarke [2], Jull [3], and Parkhurst [4].

No significant relationship was found between annual egg-production and the mean annual egg-weight by Hadley and Caldwell [5], Atwood [6], Atwood and Clarke [2], Jull [3], or Parkhurst [4].

Thompson [7] examined the records of 3,937 White Leghorn pullets for correlation between winter and annual production. He regarded the large number of records as a fair cross-section of the possible universe, and later also derived a series of regression equations for prediction purposes. A review of existing literature on short-term recording in relation to full-year recording is given by Thompson and need not be repeated here.

Short-time recording during a certain period of the year when the weight of egg laid approximates to the average annual weight has recently received attention. Jull [8] proposed the weighing of the first ten eggs of March and observed that, although this figure was applicable to a group of birds, it was unreliable when applied to individual birds. Of the 40 birds included in the experiment, 19 did not lay during every month of the eleven for which the experiment lasted, and were therefore not considered.

Maw and Maw [9] concluded from the results from 74 single-comb White Leghorns that the weighing of the first ten eggs laid in the fifth month gives a reliable estimate of the average annual egg-weight.

General.—It is fully recognized by the writers that the number of birds in the three groups was too small to obtain results sufficiently reliable for general application. In so far as the correlation coefficients here presented are in agreement with those obtained by other workers

using a very much larger number of birds, the significance of the results is rather enhanced, as they then hold good even when a small number of birds of comparatively large variability of weight and production is considered. On the other hand, where results are obtained that differ from those of workers who used a larger number of less variable birds, little significance can as yet be attached to them.

TABLE 1. *Correlation Coefficients (r) of Various Characteristics of Pullets*

Factors correlated	*Group I*	*Group II*	*Group III*
1. Number of eggs per annum and average annual weight of eggs per bird . .	-0.198 ± 0.23	-0.118 ± 0.24	0.26 ± 0.23
2. Maximum body-weight and average annual weight of eggs per bird . . .	0.263 ± 0.22	0.534 ± 0.17	0.462 ± 0.19
3. Average body-weight and average annual weight of eggs per bird . . .	0.306 ± 0.21	0.435 ± 0.20	0.338 ± 0.21
4. Average monthly body-weight and average monthly weight of eggs per group .	0.939 ± 0.028	0.942 ± 0.029	0.939 ± 0.029
5. Winter production and annual production per bird .	0.803 ± 0.085	0.824 ± 0.078	0.700 ± 0.12
6. Average weight of winter-produced eggs and average annual weight of eggs per bird	0.667 ± 0.127	0.608 ± 0.158	0.603 ± 0.150
7. Number of days of winter gap[1] and annual production per bird	-0.687 ± 0.12	-0.522 ± 0.18	-0.712 ± 0.12
8. Difference in weight of last ten eggs before winter gap and first ten eggs after winter gap and number of days of winter gap . . .	0.770 ± 0.096	0.781 ± 0.097	0.834 ± 0.076

[1] 'Winter gap' as applied here denotes the number of days reckoned from the last egg laid by the pullet before she goes into a partial moult up to the first egg laid after the moult.

Correlation between Number of Eggs per annum and the Average Annual Weight of Eggs

Table 1 shows that the coefficient of correlation between annual numerical production and average annual egg-weight is -0.198 ± 0.23, -0.118 ± 0.24, and $+0.26\pm0.23$ for Groups I, II, and III respectively. Again the standard error has been used, and it is evident that there is no significant correlation between the above physical factors. The non-significance of the correlation is in accordance with the results of most workers. It is of interest that Groups I and II show a negative correlation, whilst Group III (high protein) shows a positive correlation. A measure of non-linear correlation was not calculated because of paucity of numbers.

Correlations between Body-weight and Size of Egg

1. *Maximum body-weight and average annual weight of eggs per bird.*—The maximum body-weight was taken as the highest weight the individual bird reached when monthly weights alone were taken during the thirteen months duration of the experiment. The correlation coefficients for Groups I, II, and III are $+0{\cdot}263\pm0{\cdot}22$, $+0{\cdot}534\pm0{\cdot}17$, and $+0{\cdot}462\pm0{\cdot}19$ respectively.

Again inconsistent results are obtained. Although all correlations are positive, only Groups II and III show significant correlations. Group I's correlation is not significant. As the maximum body-weight is reached by most birds during the period when production is at its heaviest, it is quite conceivable that with the heavy drain of protein for egg-production the low protein-content of the mash provided insufficient protein for normal increase of body-weight. Part I of this paper shows that the weight of egg was not influenced by the varying amounts of protein ingested. Hence the non-significance of the correlation for Group I can perhaps be attributed to the fact that at the height of production there was an adverse nutritive balance of the diet, and the birds could not ingest sufficient protein for increase of body-weight to a normal maximum and also for production.

2. *Average body-weight and average annual weight of eggs per bird.*—Groups I, II, and III have correlation coefficients of $+0{\cdot}306\pm0{\cdot}21$, $+0{\cdot}435\pm0{\cdot}20$, and $+0{\cdot}338\pm0{\cdot}21$ respectively.

The relative positions of the coefficients are the same as when the maximum body-weight is correlated with the average annual egg-weight. A higher coefficient is obtained in Group I, but is still not significant. The coefficient for Group II is lower but still significant, whilst in Group III it has fallen below significance. This would show that although both maximum and average body-weight show positive correlations with average annual egg-weight, they differ as measures of body-weight in their relationship with average annual egg-weight.

3. *Average monthly body-weight and average monthly egg-weight per group.*—Very high coefficients of correlation are found between the average body-weight for each month and the average weight of eggs for the same month, viz. $+0{\cdot}939\pm0{\cdot}028$, $+0{\cdot}942\pm0{\cdot}029$, and $+0{\cdot}939\pm0{\cdot}029$ for the three groups respectively.

This is to be expected, for, as previously shown (Pt. I, p. 226), there is a marked relationship between monthly variations in body-weight and size of egg during the first year of production of a pullet.

Correlations between Winter and Annual Production

The season termed 'winter' does not comprise the true winter months, but March, April, May, and June. During these months production is at its lowest and most pullets go into a partial moult.

1. *Winter production and annual production.*—The correlation between these two factors is very high and significant, being $0{\cdot}803\pm0{\cdot}085$, $0{\cdot}824\pm0{\cdot}078$, and $0{\cdot}700\pm0{\cdot}12$ for the respective groups.

These results are similar to those of most workers. Unfortunately,

owing to the pronounced influence of the wet winter months on the production of birds in the College Poultry Division and the small number of birds in each group, no attempt can be made at setting a numerical standard of winter-produced eggs to serve as a criterion for the annual production. The fact that the correlation coefficients are very high would indicate that a fairly accurate standard could be laid down.

2. *Average weight of winter-produced eggs and average annual weight of eggs per bird.* The correlation coefficients for the above factors are $0{\cdot}667 \pm 0{\cdot}127$, $0{\cdot}608 \pm 0{\cdot}158$, and $0{\cdot}603 \pm 0{\cdot}150$ for Groups I, II, and III respectively; the correlations being significant.

Here also the effect of the environmental and experimental conditions cannot be gauged; therefore no standard weight is suggested for winter-produced eggs as a criterion of annual production.

The recording of all pullets through the year is a task demanding more time and labour than the average poultry-breeder can afford. Many breeders in this country record only during the winter months. Comparatively, this is a much smaller task, for during these months egg-production is at its lowest. The fact that there are significant correlations between the number and size of eggs produced in winter and the number and size produced in the whole year would support the system of short-time recording, which, although not so accurate as yearly recording, would find more general application. Given sufficient data, standards for size and number of winter-produced eggs could be established to serve as a basis similar to the numerical-production table published by Thompson [7] for selection for breeding.

3. *Winter-gap period and annual production.*—For Groups I, II, and III the correlation coefficients are $-0{\cdot}687 \pm 0{\cdot}12$, $-0{\cdot}522 \pm 0{\cdot}18$, and $-0{\cdot}712 \pm 0{\cdot}12$. Most pullets in the College Poultry Division go through a partial winter moult, and these coefficients were calculated in order to decide which of the two factors, 'winter production' or 'winter gap' (cf. p. 314) would be the more reliable factor as a measure of annual production.

It will be noticed that these values of r are high and significant, but negative, showing that the shorter the moulting-period the higher the total annual production. Comparing these values with those obtained for winter production, we find the latter are higher and also more reliable. From a practical view-point it would be more logical to record laying dates than non-laying dates.

Short-period Recording instead of Yearly Recording

With the constant variation in the size of egg, it is evident that during a certain period of the year the pullet must lay eggs of a size which closely approximates the average annual size. Jull has suggested the first 10 eggs of March, whilst Maw and Maw have suggested the first 10 eggs of the fifth month of production.

An attempt was made to apply these suggestions to the foregoing records. It was immediately found inapplicable to individual birds, as

the majority were in a partial moult and not laying during the fifth month after production commenced. Jull seemed to find the same difficulty.

With each bird's record-sheet available, the averages were calculated of the last 10 eggs before laying ceased, and of the first 10 eggs after laying again commenced. From a practical standpoint it is impossible to record only the last 10 eggs, as one does not know when the hen will cease laying. The recording of the first 10 eggs when laying recommences can be practically carried out. It was found, however (see Table 2), that of the 55 hens only 3 laid without ceasing and only 2 others had not yet reached the average annual weight. For 50 birds, therefore, the average weight of the first 10 eggs was higher than the average annual weight.

TABLE 2. *Differences between Average Weights of Short-time Recordings and Mean Annual Weight of Eggs*

Difference between mean of last ten eggs before winter gap and annual mean weight			*Difference between mean of first ten eggs after winter gap and annual mean weight*		
Group I	*Group II*	*Group III*	*Group I*	*Group II*	*Group III*
−3·92	−2·83	−5·29	4·49	0·36	3·83
0·04	−9·98	No winter gap	3·60	4·22	No winter gap
0·34	−8·39	−6·10	4·60	2·24	3·12
−3·45	−2·56	0·30	3·82	−0·52	4·20
−9·14	−7·82	−3·30	−0·34	4·76	1·57
−1·73	−7·02	0·87	1·46	4·41	5·21
−6·06	No winter gap	−4·82	2·06	No winter gap	4·84
−4·82	−4·57	1·26	4·84	3·50	3·21
0·30	0·11	−0·35	6·92	5·22	1·69
−3·20	−8·38	−4·59	3·71	3·86	6·40
−8·15	−0·30	−2·63	2·74	4·91	5·25
1·87	−5·72	1·77	5·15	3·93	5·04
0·25	−6·21	−0·37	5·03	4·51	4·47
1·14	1·19	0·71	4·04	5·62	6·47
−6·05	−1·77	−3·88	4·76	1·15	7·30
−1·0	−1·99	−3·16	2·80	1·64	0·98
−10·41	−1·42	2·40	0·49	4·79	7·98
−4·56	1·49	−1·23	4·92	6·10	5·06
−1·60	..	..	4·23	..	..

A minus sign indicates that the average weight of the ten eggs is smaller than the average annual weight.

Seventy-two per cent. of the hens had not reached the average annual weight with the last 10 eggs before going into moult. From the above it is clear that the majority of birds in this experiment did not lay during that period when they would be laying eggs of a weight equal to the average annual weight. Therefore under conditions such as those under which these birds were kept, no short-period recording was found which could give a reliable estimate of the average annual size of egg.

To ascertain what effect the duration of the non-laying period had on the size of the eggs subsequently laid, the correlation coefficient was calculated between winter-gap period and the difference in weight of the average of the last ten eggs before cessation of laying and the first 10 eggs after laying recommenced. The values for r for Groups I, II, and III were $+0{\cdot}770 \pm 0{\cdot}096$, $0{\cdot}781 \pm 0{\cdot}097$, and $+0{\cdot}834 \pm 0{\cdot}076$, which are all positive and highly significant. Expressed differently, the longer the non-laying period the heavier are the first ten eggs when laying recommences.

One could conclude from the above that the inherent ability of gradually increasing the size of egg laid increases irrespective of the hen producing or not.

Conclusions

1. No significant correlation was found between the numerical production and the average annual egg-weight.
2. All three groups showed a positive correlation between maximum body-weight and average annual egg-weight, but those of the medium- and high-protein groups were alone significant.
3. Practically the same result was obtained when average body-weight was correlated with egg-weight, except that r for the high-protein group now also fell below significance, showing that in this experiment these two measures of body-weight differed in their relationship with egg-weight.
4. There was a positive, highly significant correlation between average monthly body-weight and egg-weight.
5. Winter-produced eggs (March, April, May, June) were highly correlated with annually produced eggs with respect to both number and size, thus indicating the possibilities of short-term recording.
6. There is also a high negative correlation between the number of days the bird ceases to lay and the annual production.
7. No period could be found when the average weight of 10 eggs was approximately equal to the average annual weight of eggs, because the moulting-period coincided with the period when such an equality would have been obtained.
8. There was a highly significant correlation between the number of days of the winter gap and the difference in the average weight of the last 10 eggs before laying ceased and the first 10 eggs after laying recommenced. This indicated that the longer the non-laying period the heavier were the first 10 eggs after laying recommenced.

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FORAGE-CROP PRODUCTION IN DRY-LAND AGRICULTURE AND ON RANGES IN WESTERN CANADA

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Introductory.—For those who are unfamiliar with western Canada it will be necessary to outline briefly the soil and climatic conditions which characterize the area discussed in this paper. Reference to the accompanying sketch-map of the three prairie provinces will serve to indicate

Sketch-map of the Prairie Provinces of Western Canada, showing Major Soil Zones and Location of Dominion Experimental Stations

1. Brown-soil zone (semi-arid, short-grass prairie).
2. Dark-brown-soil zone (semi-arid to sub-humid prairie).
3. Black-soil zone (sub-humid 'parkland').
4. Grey-soil zone (sub-humid wooded land).

▲ Location of Dominion Experimental Station.

the relative positions of Manitoba, Saskatchewan, and Alberta in relation to Ontario on the east, British Columbia on the west, and United States on the south. This map was very kindly prepared for the writer by Mr. H. C. Moss, Soils Department, University of Saskatchewan, and may be regarded as authentic in respect to the zoning of major soil types. The dotted line separating Zone 3 from Zone 4 could have been taken,

until comparatively recent years, as approximately the northern limits of settlement, but now a considerable area in Zone 4, especially in Saskatchewan, has been 'homesteaded'. Practically all of this land is wooded, and as yet the clearance per farm is small. The main cultivated area comprising Zones 1, 2, and 3 extends from the eastern boundary of the Red River valley in Manitoba to the foot-hills of the Rocky Mountains in Alberta, and from the 49th parallel of latitude for a distance northward of about 350 miles.

The major soil zones, as outlined in the sketch-map, reflect soil differences associated with variations in climate and native vegetation. The brown-soil zone is a semi-arid country of short-grass plains with an annual precipitation of 11 to 14 in. The moisture-efficiency in this zone is low, owing to relatively high mean temperatures and warm, drying winds. A considerable proportion of this area is devoted to ranching, more especially the western portion of Alberta and the south-western corner of Saskatchewan. Most of this area, which lies in Saskatchewan, is, however, devoted to the production of wheat. Farming practices adapted to extensive cultivation and approved methods of moisture-conservation are therefore of the utmost importance.

Zones 1, 2, and 3 form a natural sequence with increases in precipitation and moisture-efficiency. Increase in total precipitation is slight in Zone 2, but more pronounced in Zone 3, with variations from 15 to 20 in. The increase in moisture-efficiency, on the other hand, is much more important, being associated with a decrease in mean temperature and a reduction in the duration and velocity of drying winds.

The northern and eastern limits of Zone 2 coincide approximately with the transition from true prairie to partially wooded prairie or 'park-land'. There is also a corresponding change from soils of a dark-brown or chestnut colour to soils that are predominantly black. Variations in precipitation and moisture-efficiency appear to be primarily responsible for these pronounced differences in vegetation and soil characteristics.

The dominant factor in crop production in all three soil-climatic zones is undoubtedly that of available moisture. In Zone 1 crop failure frequently results from drought, and this also occurs to a somewhat less extent in Zone 2. Even in Zone 3 moisture is the main factor limiting plant-growth, but moisture conditions on the whole are here much more favourable than in Zones 1 and 2. Variations occur also from year to year in the incidence of favourable and unfavourable moisture conditions, as in 1934, when the area affected by drought was much more extensive than usual, and the centre of greatest severity was farther to the east.

Seasonal variations in the annual precipitation are considerably greater than the zonal variations. The greatest amount of precipitation recorded in one year has been from two to four times greater than the lowest, depending upon location. Long-time precipitation trends show that wet and dry years seldom occur singly, and that more or less well-defined cycles can be distinguished in which several years of more than average rainfall alternate with several years of comparatively dry weather. Precipitation, of course, is notoriously variable from year to year all over the world, and western Canada is no exception in this respect. It is only

because a surplus of subsoil moisture never occurs in Zones 1 and 2, and very rarely in Zone 3, that the seasonal variations in precipitation often make all the difference between years of drought and years of plenty.

In addition to limited supplies of available moisture, the rather short growing-seasons and extremes of temperature, both daily and seasonal, impose rigorous restrictions on the choice of forage crops. Most of the commonly grown grasses and clovers, including timothy, cocksfoot, Italian and perennial rye-grasses, red clover, alsike, and white clover, are ill adapted, either because of their moisture-requirements or lack of winter hardiness. Only in a few restricted areas of Zone 3 can such crops as timothy, red clover, and meadow fescue be used to advantage.

Maize is grown to a considerable extent in southern Manitoba, more especially in the Red River valley south of Winnipeg, where early-maturing dent varieties produce good fodder crops, due to the lower altitude and mean temperatures that are higher than elsewhere. This crop is also on the increase in southern Alberta, but only the very early flint and dent varieties are satisfactory because of the higher elevation of this area. Across the northern settled portion of the three prairie provinces the growing of maize has not attained much success. Throughout the Park Belt and adjacent plains sunflowers provide a high-yielding ensilage crop, but the labour required in handling is heavy, and the absence of silos for storing the fodder has, to date, prevented the sunflower crop from becoming of any importance.

Hay and Pasture Crops

The amount of cultivated land devoted to hay and pasture crops in the three western provinces has been relatively unimportant as compared with the total of 40 million acres which are seeded annually. Statistics show that hay and pasture occupy roughly 5 per cent. of the land devoted to field crops, about half of which, or one million acres, is seeded pasture. These figures, taken by themselves, are, however, misleading, in that they do not include cereal crops that are pastured or harvested in the sheaf for hay. The latter, in western Canada, is very important. Oats alone are grown more extensively for 'feed' than all other forage crops combined. The estimated area of natural pasture is 29 million acres, of which about 7 million acres of ranching country are leased for grazing purposes, mostly in Zone 1.

There are natural and obvious reasons for the disparity between cereal and forage crops in a new country like western Canada, but soil and climatic conditions cannot rightly be classed among them, except in those areas where lack of moisture makes even grain-growing hazardous. Even this disability is being overcome by the introduction of forage plants that are exceptionally drought-resistant. Everywhere the yield of forage is limited by the amount of available moisture, and this is to be expected. On the other hand, the soil in general is exceptionally favourable for grasses and legumes, being naturally fertile and plentifully supplied with lime. Fortunately, there is available a sufficient number of species that are winter-hardy and remarkably well adapted to the prevailing conditions.

Perennial grasses.—There are three species of perennial grasses that are highly adapted to this area. These are brome grass, *Bromus inermis*; slender wheat-grass, *Agropyron tenerum*; and crested wheat-grass, *Agropyron cristatum*. A choice between these should be governed chiefly by the purpose for which the grass is grown, the soil type, and moisture conditions. Broadly speaking, crested wheat-grass is highly adapted to the brown-soil zone, whilst brome grass and slender wheat-grass are best adapted to the dark-brown and black-soil areas.

Crested wheat-grass, being exceptionally resistant to drought, will do better than the other two where this property is of first importance. Western rye-grass does exceptionally well in the Park Belt, and many farmers there prefer it to brome grass because it is not stoloniferous and is therefore easy to control by ploughing. Generally speaking, the growing of slender wheat-grass is on the decrease, because its performance has been disappointing in the recent dry seasons. This is particularly true of the prairie sections. Brome grass has been the most important grass in the central or dark-brown-soil area, because it withstands drought better than slender wheat-grass and is altogether a better pasture crop. The use of brome grass is increasing, especially in Manitoba, where it is grown more extensively than any other species. Although it is sometimes discounted by farmers in the more humid districts and on heavy soil owing to its strong underground stems, it deserves to be grown even more widely than it has been because of its productiveness, palatability, and high nutritive value. It thrives on a wide range of soil types, being particularly useful on the lighter soils, where it should be grown in preference to slender wheat-grass. Brome grass is a good seed-producer and the herbage remains green after the seed is ripe. Both for hay and pasture it is a superior grass.

Crested wheat-grass has been grown in a small way in western Canada during the last few years, but only now is it coming into general use. Experimental work with this species indicates that it is one of the most valuable species that has ever been introduced into western Canada, and that it promises to provide a much-needed perennial hay and pasture crop for the semi-arid sections of the West. At Saskatoon, crested wheat-grass has yielded at least as much as brome or slender wheat-grass over a six-year period. In general, it may be said that crested wheat-grass will produce more or less than slender wheat-grass or brome grass in proportion to the abundance or scarcity of available moisture. In the very dry season of 1931 it produced double the yield of either brome or slender wheat. It is high in feeding-value, withstands grazing well, does not become root-bound, provides feed in the early and late parts of the season, and produces seed abundantly.

Alfalfa.—Alfalfa is highly adapted to the black-soil zone or Park Belt, and in favourable seasons good crops are secured also on the better soils in Zone 2. Western Canada is self-supporting with respect to seed-production of hardy strains, of which by far the most important variety is 'Grimm'. When sufficient attention is given to proper management of the crop there is seldom much trouble with winter-killing. In favourable seasons two crops of hay can be taken, but very often it is more

profitable to take only one. The latter practice ensures an adequate storage of root-reserves, and provides the best guarantee against winter injury. Cutting of the second crop is hazardous when it is done just early enough to permit of some autumn growth, but too late to enable the plants to replenish their root-reserves.

Mixtures versus single species.—For the most part the different kinds of perennial grasses and alfalfa are grown in pure culture, but many farmers now seed the grasses with alfalfa in a mixture, and this practice is on the increase. In an experiment extending over eight years which the author conducted at the University of Saskatchewan, slender wheat-grass, brome grass, and alfalfa were compared from the standpoint of yield of hay. Each crop was seeded alone and each was combined with the other in mixtures. The results of this test, which included 18 crops of hay, showed no significant differences between the yields of any one of the three crops, nor between these and a combination of the two grasses. This was explained on the basis that moisture was always a limiting factor in growth and that each of the three species separately, and the mixtures, used up annually all the available moisture. Thus the yields were strictly limited.

Mixtures of slender wheat-grass and alfalfa, and of brome grass and alfalfa, on the other hand, did yield significantly more than any of the single species seeded alone, or of the two-grass mixture. This indicated an increase in moisture-efficiency when the grass and legume were grown together. There was also an obvious difference in vigour of growth and depth of green colour between the grasses growing in association with alfalfa and of those growing by themselves. Apparently the grass was benefited by the alfalfa, presumably because of the latter's ability to utilize atmospheric nitrogen. By taking samples for chemical analyses in each of two years it was found that the brome grass growing with alfalfa contained 16 per cent. more protein than it did when growing alone. The increase in protein shown by slender wheat-grass in association with alfalfa was still greater, being almost 40 per cent. Not only therefore did the grass-alfalfa mixture give a significantly greater quantity of herbage, but the feeding-quality of the grass itself was improved and that of the mixture enhanced by the legume constituent.

One complete series of these plots, seeded in 1926, has been retained until the present time, and in 1934, the eighth crop-year and an exceptionally dry season, the mixture of brome grass and alfalfa was more than twice as productive as the brome grass on adjacent plots, and considerably more productive than the alfalfa alone. The proportion of brome grass and alfalfa in the herbage has remained fairly constant from year to year, showing that these species are quite compatible. The mixture of slender wheat-grass and alfalfa, on the other hand, has not maintained its productivity because the grass constituent has suffered severely through the intervening years, several of which have been particularly dry.

Sweet clover.—Sweet clover has been a very welcome and valuable addition to the forage crops that can be grown in western Canada. It is a biennial and therefore must be seeded each year. The crop is utilized

for hay or pasture in the year following seeding. Two crops of hay can sometimes be secured in a single season, but the more common practice is to cut one crop of hay and pasture thereafter.

Sweet clover can be grown successfully over practically all of the western plains area. Few crops are adapted to such a wide range of soil and climatic conditions, and probably none will produce as much good pasturage. Sweet clover has been the salvation of many a farmer in very dry years, giving a fair yield under conditions which resulted in complete failure of perennials. When moisture is plentiful, on the other hand, sweet clover will take full advantage of it.

Good stands of sweet clover are difficult to obtain under unfavourable moisture conditions, such as occur frequently in the brown-soil zone. This is especially true if the clover is seeded with grain as a nurse-crop. Perhaps the most frequent cause of failure with sweet clover is seeding too deeply into loose soil. This is fatal. The grower of sweet clover must learn the all-important principle that shallow seeding on very firm soil is the best insurance that he can have for securing good stands of this crop.

Rather severe losses of sweet clover have occurred from time to time from the ravages of cutworms, which are very fond of this species, and also from certain native soil organisms that cause rotting of the roots in the early spring of the second season. The latter have not been troublesome in Manitoba but rather severe in Alberta, and the injury is much worse in some years than in others. Apparently much depends on the vigour of growth and size of roots as they go into the winter; the larger the roots the less is the injury likely to be. It has been found that seeding without a nurse-crop not only produces larger yields the following season but also greatly reduces the hazards from root-rot. Although the practice is not common, there is much to be said for seeding in some sections of the country without a nurse-crop in June, after the danger from cutworms is past, rather than seeding with grain in the early spring. When sweet clover is grown with a nurse-crop early seeding is preferable.

Crops for alkali soils.—In many parts of the West one frequently encounters soils in which the concentration of alkali salts tends to be excessive for plant-growth. Based on tests which were conducted at the University of Saskatchewan, the forage crops most tolerant of alkali salts were found to be sweet clover, slender wheat-grass, brome grass, and crested wheat-grass.

Difficulty is sometimes experienced in securing a stand of sweet clover on alkali soil because the seedlings are liable to be injured in the early stages of growth, but when they have become established the clover is much more tolerant and will grow where the alkali salts are toxic for cereal crops. If the sweet clover is grown continuously for three or four years on such land, the condition is frequently sufficiently improved so that oats or even wheat can be produced. A top dressing of well-rotted manure 'disked' into the land before seeding helps considerably to get sweet clover started.

When seeding-down a field which is spotted with alkali, it is a very good idea to use a mixture rather than a single species of alkali-tolerant

plants. The chances of getting a satisfactory stand are better, and each component of the mixture will tend to become established where it is best suited. A good mixture for this purpose consists of 7 lb. of slender wheat-grass, 7 lb. of brome grass, and 10 lb. of sweet clover, making 24 lb. of seed per acre.

Annual crops for hay and pasture.—The importance of annual forage crops in western Canada can scarcely be over-estimated. Of these, oats are by far the most important and the most valuable for feeding stock, whether as hay or pasture. They excel in both yield and quality of forage, and few, if any, other crops are as satisfactory when used as the sole ration for horses and cattle. Barley is valuable also as a feed-crop, but bearded varieties are objectionable. Spring rye produces a crop of somewhat inferior hay which sometimes comes in handy when feed is scarce, because it can be cut early. Autumn rye has most value as a pasture crop in late autumn and early spring, but it may also be harvested for hay. Peas are grown with oats to some extent in the more humid districts and with excellent results. Millet is useful as a quick-growing catch-crop to seed late, but it does not do well under dry conditions, and it is inferior to oats in yield and feeding-quality.

Reliance must be placed on cereals also for annual pasture. Here again oats are the best, but either wheat or barley in admixture with oats may be seeded with good results. A favourite mixture for pasture in many parts of the West is a combination of two bushels of oats and one of autumn rye per acre; the latter tends to produce a leafy bottom growth during the first year, and this provides good pasturage late in the season after the oats are done.

Seed-Production

Conditions in the prairie provinces are very favourable for growing seed of all the important forage crops that are adapted to that area. Sweet-clover seed is grown extensively in all three provinces. Some slender wheat-grass seed and brome-grass seed is grown in Alberta and Manitoba, but Saskatchewan produces about three-quarters of the supply. Until recently, most of the alfalfa seed was grown under irrigation in the district which centres about Brooks, Alberta, but it is now being produced in considerable quantity by all three provinces. With crested wheat-grass it has been found that in Zone 1, where it is best adapted and most useful, the supply of available moisture after the grass has headed may be insufficient properly to fill the seed. The seed crop, therefore, may be a failure, and even in favourable seasons the yield is likely to be much less than if the grass were grown farther north in the Park Belt, where better moisture conditions prevail. Whereas a good crop of crested wheat-grass seed in Zone 1 may be about 200 lb. per acre, it is not uncommon in Zone 3 to secure 500 or 600 lb. of seed per acre. The bulk of the seed, therefore, is likely to be grown in the northern part of the three prairie provinces and used in the southern part. For seed-production this grass is grown in inter-tilled drills about 3 or $3\frac{1}{2}$ ft. apart.

What has been said with respect to crested wheat-grass applies also

to brome grass, slender wheat-grass, sweet clover, and alfalfa. In the Park Belt moisture conditions are exceptionally favourable for seed-production, whereas in the driest parts of the prairie area seed-production of these crops is precarious.

Methods of Seeding

In seeding-down with grasses and legumes it is of vital importance to get good establishment. This presents certain difficulties in semi-arid and sub-humid areas, where good rains are apt to be somewhat infrequent and the top-soil rapidly dries to a depth of 1 or 2 in. In very dry seasons it is almost impossible to secure good stands of grasses and legumes, but in most years there is sufficient moisture near the surface in the early part of the season and sufficient precipitation from time to time during the spring months to ensure success if certain fairly well-established principles are observed.

Seeding-down with a nurse-crop of grain is a common practice, because a crop of grain or sheaf feed is secured in the year of seeding. On land that is weedy or liable to soil-drifting also, a nurse-crop has obvious advantages. The usual practice is to mix thoroughly grass seed with grain and sow both together with the ordinary grain-drill. A nurse-crop, however, makes heavy demands on the soil moisture, and competes so strongly with grasses and clover that the latter may be completely killed in a dry season. Therefore, if a nurse-crop is used in the prairie sections which are less favourably situated with respect to moisture, early seeding on land which has reserve moisture, such as summer fallow, is highly desirable.

It frequently happens, however, that seeding of grasses and clovers is done on land which has little or no reserve moisture, and which in the normal grain-rotation would be fallowed in summer. Under these circumstances grasses and clovers can be started with greater safety if no nurse-crop is used. The land should be ploughed or surface-worked early in the season, packed to start weed seeds, and kept clean until after rains, which are most likely to occur in June; then, if the grass and clover seed is shallow drilled, without a nurse-crop, there is an excellent chance of getting a good stand well established before fall. This applies particularly to brome grass, slender wheat-grass, alfalfa, and sweet clover, but with crested wheat-grass it is always safer to seed very early whether with or without a nurse-crop, because the young seedlings of this species get started much better in cold weather.

In seeding grass and clover seed, drilling is preferable to broadcasting, but with the former method great care is necessary that the seeds are not sown too deeply. This is difficult to avoid with a grain-drill unless the soil is very firm and unless all pressure is released from the disks which act as soil-openers for the seed. The maximum depth of seeding for crested wheat-grass, sweet clover, brome grass, alfalfa, and slender wheat-grass should be $\frac{3}{4}$, 1, $1\frac{1}{2}$, $1\frac{1}{2}$, and 2 in., respectively. These depths are less than that commonly employed for cereals. A method of seeding with a nurse-crop which gives excellent results but requires somewhat more work, is first to drill the grain separately, and then to

drill the grass or legume seed crosswise. In this way both can be seeded at depths which are most suitable.

Shallow seeding on well-prepared and very firm soil is of first importance in securing good stands, especially of crested wheat-grass and sweet clover. Many failures result from lack of appreciation of the importance of these simple pre-requisites. Even with the best intention it is often difficult to drill shallow enough on spring-prepared land, because the weight of the drill tends to force the disks too deeply. This is the case to such an extent that with crested wheat-grass and sweet clover, broadcasting is often the safer method, particularly when seeding can be done early while moisture is still close to the soil surface.

Range Investigations

An extensive study has been made during the last six years at the Dominion Range Experiment Station, Manyberries, Alberta, on the effect of different systems of range-management on the native vegetation. These methods include continuous, deferred, and rotational grazing. Over-grazing has been responsible, more than any other factor, for the depleted condition of certain range areas. It seems clear that the most economical way of restoring depleted pastures on the range is to protect them during the spring and summer months and then to graze in the autumn and winter after the seeds of native grasses have been shed. If the pasture is badly depleted this method of deferred grazing should be adopted several years in succession.

Although deferred and rotational grazing is recommended, the range should not be divided into units which are too small, or the grass-cover will be injured by excessive tramping. Uniform grazing can be obtained by good distribution of watering-places and salt-boxes. Areas that have been closely grazed in autumn should not be pastured in the spring. On spring pastures there should be a carry-over of at least 30 per cent. of the previous year's grass.

Many tests have been made on the re-seeding of depleted range land. These have proved successful only where the native grasses have been almost completely killed out. Where there still remains even a thin stand of native grass it is probably better to protect the area from grazing, or to graze only during late autumn, thus allowing the grass to go to seed and spread naturally.

Seeds of many species of grasses and legumes have been tried for re-seeding fields which were once cultivated and since abandoned. Crested wheat-grass has given by far the best results. Good stands of this grass have been obtained by scattering the seed among the weeds, either late in autumn or early in spring, giving a single disking after seeding. With this treatment crested wheat-grass produced a good growth in 1934, after being closely grazed each summer from early spring until late autumn for six years in succession.

Charted quadrats and permanent enclosures have been established on each of the nine fields used in the investigation of grazing capacity, and also on four large fields assigned especially for this study. In addition, the vegetation-cover of each field was carefully examined three

times each season: before grazing began, about mid-season, and at the time the cattle were removed from the field. In general it was found that fields grazed at the rate of 20 acres per head were much overgrazed. Those grazed at 30 acres per head were slightly overgrazed, whilst pastures grazed at 40 acres per head were undergrazed.

The identification of native forage plants of the short-grass plains has been completed, and a key has been prepared for the grasses of the prairie provinces. Considerable attention has been given to the effect of climatic conditions on plant-growth and to other ecological problems.

Chemical analyses of the native species show that they are high in protein when in the leaf-stage, and that at this time they contain also sufficient phosphorus and calcium to meet the animals' requirements. As the plants approach maturity there is a marked drop in nitrogen and phosphoric acid. As cured grass for late autumn and winter grazing, there is a deficiency in the phosphorus-content of these species. Calcium-content does not drop to any considerable extent. To overcome this lack of phosphorus in the native herbage some stockmen are now beginning to feed mineral supplements of bone-meal or monocalcium phosphate.

The production of winter feed on the range is a matter of considerable importance, as reserves of hay are essential in case winter grazing conditions become difficult. The development of comparatively small local irrigation schemes by the construction of dams for impounding the spring run-off water has been found to be one of the best ways of solving the winter-feed problem. With a comparatively limited application of water by surface-flooding, excellent crops of alfalfa hay can be produced. Alfalfa is by far the best cultivated crop for this purpose. In certain places the native grasses produce well where water is supplied. Some ranchers, in favourable locations, practise dry-land farming. The land is alternately cropped and summer-fallowed to conserve moisture, and such crops as the cereals, sweet clover, and maize are produced for forage.

In southern Alberta there are several large-scale irrigation projects not far removed from the ranching areas, and there is a growing tendency for the irrigation farmer who can grow large quantities of feed, on the one hand, and the rancher who produces the animals, on the other, to work out arrangements that are mutually advantageous, involving the establishment of winter feed-lots close to crop-production areas.

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PASTURE STUDIES VII. THE EFFECT OF FERTILIZATION ON THE NUTRITIVE VALUE OF PASTURE GRASS

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Introductory.—The literature dealing with this subject has been reviewed and discussed in an earlier paper [1] where the general reasons for this series of studies[1] were outlined.

The failure of previous studies adequately to explain observed differences in the nutritive value of herbage from different pastures, and of differences resulting from the application of fertilizers, led to the suggestion that quality of protein might be a factor of importance and one hitherto disregarded in pasture studies. Accordingly, a series of feeding tests was planned to determine, if possible, (1) whether pasture herbage might be deficient in any one of the essential amino acids, and (2) whether the oft-observed increase in nutritive value due to fertilizer treatment might possibly be the result of an improved amino-acid balance of the herbage.

It was realized, of course, that fertilization of pastures often affects the botanical composition of the mixed herbage, and, therefore, that tests would also need to be made on the pure species, both untreated and fertilized, which contributed to the mixed herbage of the pasture studied. Arrangements were made to secure such clippings from the experimental plots of the Agronomy Department.

Experimental.—The plan of the experiment involved the feeding of grass clippings with and without supplements of single purified amino acids or combinations of them.

The difficulty in obtaining grass clippings in large quantities and the cost of the amino-acid supplements necessitated the use of laboratory animals in this study, and rabbits were chosen as the most suitable because of the similarity of the natural diets of domestic rabbits to those of farm ruminants. Excepting as otherwise noted, rabbits raised from a small breeding unit maintained for the purpose, and weaned at approximately seven weeks of age, were used in all tests of this series. A preliminary feeding-period of from one to three weeks was usually found necessary to accustom the rabbits to the individual cages and the finely-ground grass.

The feeding trials herein reported represent but the first trials of the series involved in the project. For these tests either crude lactalbumin or cystine-fortified casein were used as supplements carrying a complete

[1] These studies constitute a part of the general pasture project undertaken at Macdonald College, and are made possible by financial assistance from the Quebec Department of Agriculture.

assortment of the essential amino acids. In so far as the single amino-acid supplements were concerned, it was decided to confine the first year's tests to cystine, partly because there was some indication from the literature that pasture herbage might be deficient in cystine, and partly because of cost.

The mixed pasture-grass clippings used in the first year's trials were obtained from pasture lands of two farms in the Eastern Townships of Quebec co-operating in the Macdonald College Pasture Project.

In the spring of 1933, one-half of each of these areas received 100 lb. of potash and 500 lb. of superphosphate (16 per cent.) per acre, and was fenced to permit controlled grazing. Three clippings were made during the season, and after each clipping cows were allowed to graze the areas. The first clipping was taken during the second week in June and represented the spring growth of grass. The pastures were then grazed for about two weeks, after which the cows were taken off to allow the grass to grow for the second clipping, which was made during the last week in July. The grass at this time was not plentiful, owing to the exceptionally dry summer, and hence no clipping was taken in August. The areas were grazed after the second clipping but were kept ungrazed about a month before the third clipping, which was made during the last week in September.

The clippings were dried in the field until in suitable condition to ship, when they were forwarded to the laboratory and drying was completed by spreading in a thin layer on the floor. When dried, the grass was ground in a hammer-mill and stored in bags until required for feeding.

The clippings of pure species of grass, obtained from plots of the Agronomy Department, were prepared for feeding in the same way as were the samples of mixed pasture herbage.

Since an accurate and detailed record of feed-consumption seemed essential in this study. individual feeding was employed. The equipment used has already been described [1].

Test I. *Timothy* v. *Reed Canary-Grass*

This test was planned to compare the nutritive value of immature timothy grass with that of immature reed canary-grass; also to determine whether the addition to these grasses of a protein of high biological value would increase their nutritive values. Besides the four rations necessary for these comparisons, a fifth, thought to be satisfactory for normal growth, was included as a check ration.

A sixty-day feeding period was used in this test. To follow the progress of the rabbits during the trial, live weights and feed-consumption were checked at ten-day intervals.

Feeds used.—The reed canary-grass and the timothy were cut from plots of the pure species in the early summer of 1933. The grass was cut when it was from 4 to 6 in. high, and as it was desired to obtain the grasses at the same stage of maturity, the timothy, which grows less rapidly, was cut about a week later than the reed canary-grass. Crude lactalbumin[1] was used as a protein supplement. The oats, linseed meal,

[1] The lactalbumin used was obtained from the Quinty Dairies, Wellington, Ontario.

and alfalfa meal were obtained from the feed-supply of the College Stock Farm.

Rations fed.—The details of the rations, together with their chemical analyses, are given in Table 1. The animals were fed *ad libitum* throughout the experiment.

TABLE 1. *Timothy* v. *Reed Canary-grass*

Rations used and their chemical composition

	Lot I	*Lot II*	*Lot III*	*Lot IV*	*Lot V*
Reed canary-grass	100	..	95	..	..
Timothy	..	100	..	95	..
Alfalfa meal	..	..	..	..	50
Oats	..	..	..	..	40
Linseed meal	..	..	..	..	10
Lactalbumin	..	..	5	5	..
Analysis as per cent. of dry matter:					
Crude protein	13·53	12·01	15·88	14·41	15·20
Ether extract	3·10	3·69	2·99	3·55	3·68
Crude fibre	27·83	26·82	26·42	25·48	22·98
N-free extract	45·27	49·39	43·77	47·69	53·07
Total ash	10·27	8·09	10·94	8·87	5·07
Ca	0·417	0·398	0·437	0·418	0·715
P	0·388	0·349	0·392	0·354	0·388

Animals used and allotment.—Twenty-five rabbits of approximately ten weeks of age were used in this experiment. They were divided as equally as possible into five lots, taking into consideration chiefly weight, sex, and condition. The average weights for each group ranged between 1,304 and 1,321 grammes at this stage. The animals were fed on their respective diets for a preliminary period of five days before the actual experiment began and the data (Appendix, Table 1) were first recorded.

Observations.—During the first ten-day period a serious loss in weight and condition occurred in the animals on reed canary-grass (Lots I and III). One animal in each of these lots died during this period. Post-mortem examination showed that both of these animals had diseased kidneys and hearts. Consequently, they were replaced on the first weigh day by two extra rabbits which had been carried as spares. The animals receiving timothy (Lots II and IV) also lost their original bloom during the first period, though they continued to grow and actually gained in weight. The animals receiving the check ration (Lot V) showed no loss in condition and grew rapidly.

As shown in Fig. 1, all lots showed gains in weight after the first period. The gains, however, in Lots I and III were small. No consistent improvement over Lot I could be noticed from the addition of lactalbumin to the reed canary-grass in Lot III.

During the third period one animal in Lot I died. Post-mortem

Analysis showed it to contain 94·7 per cent. dry matter, having a percentage composition of crude protein 59·28, ether extract 0·89, fibre 0·47, nitrogen-free extract 16·17, ash 23·19 (Ca 8·15, P 4·51).

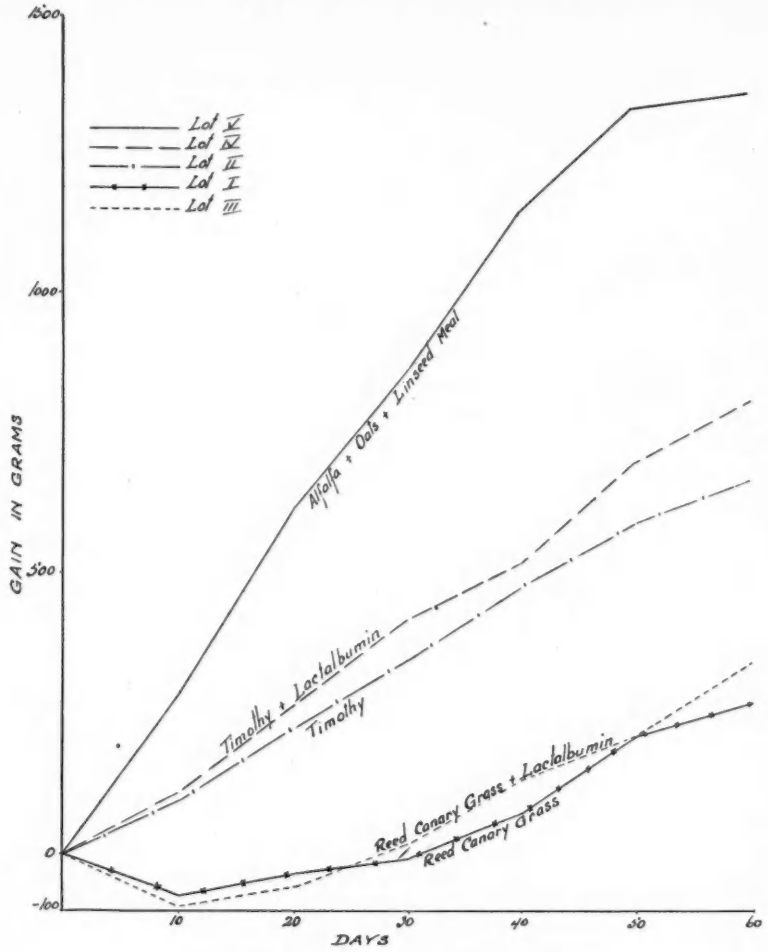

FIG. 1. Timothy *v.* Reed Canary-Grass.

examination showed no abnormalities except thin brittle bones and precipitated calcium oxalate in the urine. The prevalence of leg injury in the remainder of the animals in Lot I was a peculiar feature in this group. Three out of the four animals were lame at various times during the trial. In no case was the injury serious, and their recovery, without treatment, was complete before the end of the trial; but the fact that it occurred only in one lot is perhaps significant.

Lots II and IV (timothy) gained consistently throughout the feeding-period and appeared healthy and in good condition. The addition of

protein to the timothy diet produced a noticeable though not a marked improvement.

The control animals (Lot V) made normal gains. At the close of the experiment they were approaching maturity and their rate of growth began to slacken.

The data.—The details of initial weights, feed-consumption, and gains, together with the statistical analysis of the gains are given in Appendix, Table 1. The gains are given in graph form in Fig. 1.

The consistency of the gains made by the animals on timothy (Lots II and IV) is noteworthy, as also is the consistent but small increase in the gains of Lot IV over Lot II, due to the addition of 5 per cent. lactalbumin. The gains of the animals on reed canary-grass (Lots I and III) showed more variability than was found in other lots.

For inclusion in the statistical analysis the gains and feed-consumption for rabbit No. 27, which died on the 16th day of the experiment, were calculated by the method of Yates [2].

Statistical analysis was applied to the data, using the method of partial regression, as described by Crampton and Hopkins [3], by means of which the combined effects on gains of differences in initial weight and differences in feed-intake of individual rabbits are removed, thus permitting an estimate of gains expected from the trial had all animals been of the same weight at the start and consumed equal quantities of feed during the test. The corrected mean gains for each lot are shown in Table 2.

TABLE 2. *Timothy* v. *Reed Canary-Grass—Mean Gains (to nearest whole gram)*

Lot I	*Lot II*	*Lot III*	*Lot IV*	*Lot V*
Reed canary-grass	Timothy	Reed canary-grass + lactalbumin	Timothy + lactalbumin	Alfalfa meal + oats + linseed meal
287	641	390	870	1,263

In this trial, and considering odds of 19 to 1 as necessary for significance, any difference between mean gains greater than 119 gm. may be taken as a real difference due to difference in the nutritive value of the ration. From this analysis it is evident that the difference between the mean gains of the animals on timothy (Lot II) and those on reed canary-grass (Lot I) is highly significant. The addition of 5 per cent. lactalbumin to the reed canary-grass (Lot III) produced no significant increase over Lot I; but the addition of lactalbumin to the timothy (Lot IV) increased the gains significantly over those of Lot II. None of the rations was so satisfactory as the check ration, as measured by gains in live weight of the animals.

Summary.—In the light of the foregoing results it seems evident that the nutritive value of immature timothy is greater than that of immature reed canary-grass. This superiority cannot be explained on the basis of quantitative differences in crude protein, calcium, phosphorus, or

total nutrients, for in these respects these grasses were very similar (Table 1). Observations during the trial, substantiated by the data on feed-consumption, showed no difference in the palatability of the two grasses as measured by the quantity eaten by the animals.

Test II. *Fertilized* v. *Unfertilized Pasture Grass*

This experiment was planned to test the nutritive value of fertilized and unfertilized pasture grass by feeding the herbage, unsupplemented, to young rabbits. The feeding-period was twenty-eight days continuously, live weights and feed-consumption being recorded at seven-day intervals.

Feeds used.—The source and preparation of the herbage used in this experiment have been described (p. 332), and the botanical and chemical composition of the herbage have already been detailed [1]. Chemically, the fertilized herbage fed to Lot I was somewhat higher in protein than that from the unfertilized areas (16·7 and 14·7 per cent. protein, respectively); other differences were small. Botanically, the fertilized herbage carried considerably more white clover and correspondingly fewer weeds.

Animals used and allotment.—Animals from the regular breeding unit were not available for this test, but it was found possible to secure from another department chinchilla rabbits of approximately ten weeks of age. They were somewhat smaller (due to difference in breed) than those used in other tests and also less uniform in size. They were allotted by pairs to two groups, weight, sex, and condition being taken into consideration.

Observations.—The chinchillas were often found more delicate than the larger breed regularly used. We were not greatly surprised, therefore, that two of the smaller animals in each group died during the first week of the experiment. Post-mortem examination revealed a diseased liver in one rabbit. This condition, however, could not have developed as a result of the experimental diet. No abnormalities were found in the other three animals.

The eight rabbits remaining, which for the most part were larger animals, adapted themselves satisfactorily to the diets. The results from the animals that died were therefore discarded and the two (one in each lot) whose pair mates had died became the fourth pair (Nos. 7 and 12).

A marked difference was noticeable during the experiment in the condition of the animals in the two lots. Those on the fertilized grass (Lot I) were in good condition throughout the trial and made fairly rapid growth. The animals on unfertilized grass (Lot II) began to fail in condition immediately after the trial had commenced. This loss in weight and condition continued for the first three weeks of the experiment, until, in most cases, the animals became emaciated. During the last period, however, every animal in the lot showed a slight increase in weight. Post-mortem examinations, made on representative animals after the experiment finished, showed the animals to be normal and disease-free.

The data.—The details of the initial weight, feed-consumption, and gains, together with the statistical analysis of the gains, are given in Appendix, Table 2.

The gains are shown graphically in Fig. 2. The difference in the mean gains of these lots is statistically significant. This analysis, however,

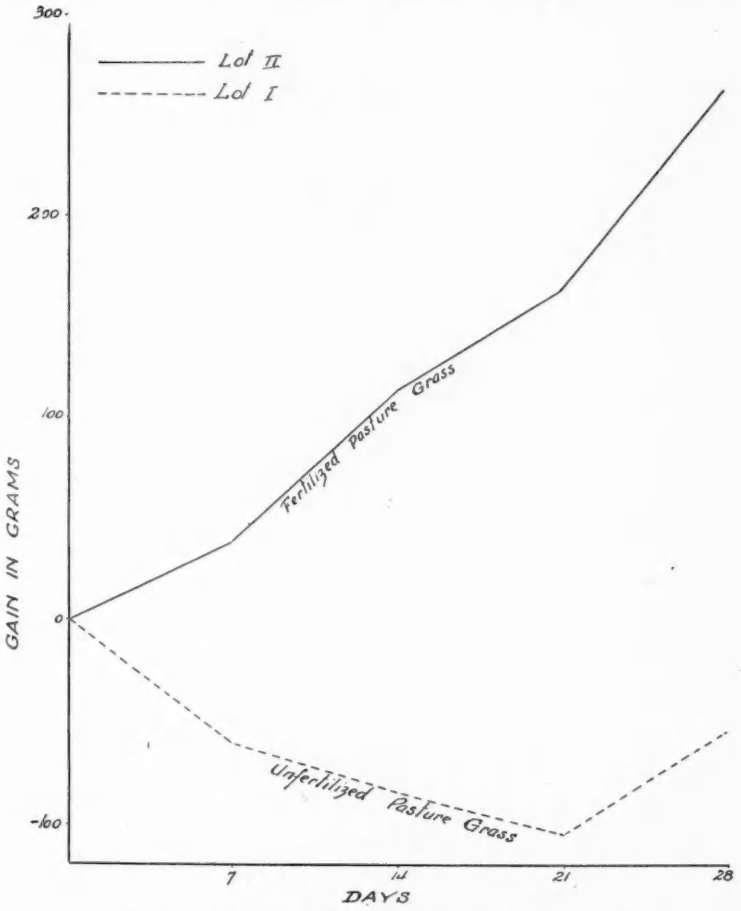

FIG. 2. Fertilized *v.* Unfertilized Mixed Pasture Herbage.

did not take into account differences in initial weight or in feed-consumption. It is realized that the average daily feed-consumption was about 4·5 per cent. higher for Lot I than for Lot II, but it does not seem likely that this small difference was responsible for the difference of some 300 per cent. in gains.

Summary.—The results of this experiment indicate strongly that

there may be a marked difference in the nutritive value of herbage from pastures treated with mineral fertilizers as compared with herbage from similar unfertilized pastures. That a part of this difference in feeding-value may be due to change in botanical composition, particularly to increase in clovers, is entirely probable.

Test III. *The Effect of Fertilization on the Quality of Protein in Pasture Grass*

In view of the marked differences in feeding-value of fertilized and unfertilized pasture herbage, found in the previous experiment, it was planned in this trial to test the possibility that quality of protein was a factor involved in these observed differences.

Results reported by Miller and Chibnall [4], and by Evans [5], suggest that perhaps pasture grass is deficient in cystine. From an amino-acid analysis of timothy, conducted in this Institution, Dyck and McKibbin [6] reported a notably low cystine-content. It was decided, therefore, to test the effect of adding purified cystine to the basal diets of both fertilized and unfertilized mixed-pasture herbage. Cystine was included in the rations of Lots III and IV at the rate of 0·4 per cent. This was equivalent to about 3 per cent. of the protein, and was the rate at which this amino acid was included, and found to give satisfactory results, in experimental diets reported by Mitchell and Smuts [7].

A mixed amino-acid supplement was also included in this test, for which purpose casein fortified with cystine was used. The cystine was added to the casein at the rate of 2·6 per cent. The cystine-fortified casein constituted 5·13 per cent. of the diets of Lots V and VI. Assuming the five essential amino acids (lysine, tryptophane, cystine, histidine, tyrosine) to represent 20·1 per cent. of the casein [8], the adjustment was equivalent to substituting the basic diet with a 1·14 per cent. mixture of these five amino acids.

Rations used.—The detail of the rations fed to each lot, including chemical composition, was given previously [1, p. 347]. Reference to Table 7 of that paper shows that a mixture of equal parts of oat-hulls and sugar was used to adjust the protein-level of the several diets approximately to that of Lot II (unfertilized grass plus salt). With the addition of the 5 per cent. casein in Lots V and VI, a rather large allowance of this mixture was necessary to maintain the protein-level wanted, with the result that the nitrogen-free extract was somewhat above, and the fibre somewhat below those of the other lots. This may partly explain the more rapid growth made on these latter diets. It will be noted also that, based on relative requirements for larger animals, there did not appear to be a deficiency of minerals (Ca or P) in any of these diets.

Rations.—The source and preparation of the herbage used as the basis of these rations have already been described (p. 332). The feed-consumption in this experiment was controlled, the amounts allowed daily per rabbit being approximately 80 per cent. of what previous trials had indicated to constitute full feeding. For the first seven days this allowance was 100 gm. of air-dry feed. For the next fourteen days

this was increased to 125 gm. During the last period it was necessary, owing to an error in a shipment of cystine, to reduce the feed-allowance to 115 gm. per rabbit per day. This reduction during the last period is clearly reflected in the growth curve. A twenty-eight day feeding period was used in this test.

Animals used and allotment.—Thirty eleven-week-old rabbits, obtained from the regular breeding unit, were used in this experiment. They were allotted to six groups, weight, sex, and condition being mainly considered.

Observations.—Marked differences in the response of the animals to the different treatments were evident immediately after the trial had started. The animals in Series A (Lots I, III, V) showed no loss in condition and continued to grow fairly rapidly. Those in Lot V, receiving the mixed amino-acid supplement, showed a considerable improvement over the other two lots. The cystine-addition in Lot III produced no noticeable immediate effect over Lot I.

In Series B more pronounced differences occurred. The animals receiving the straight unfertilized grass diet (Lot II), and those receiving the addition of cystine (Lot IV), lost condition, the loss in the first period being less severe for Lot IV, receiving the cystine, than for Lot II.

The addition of the mixed supplement in Lot VI resulted in a marked improvement over the other lots of this Series. These animals, with the exception of one, compared favourably with those receiving the fertilized grass plus the same supplement (Lot V).

Nine days after the experiment had started one animal in Lot II died. This rabbit was in an extremely emaciated condition. No abnormalities were found on post-mortem examination; consequently it seems that death was due to the unsatisfactory diet.

During the remainder of the experimental period there was no noticeable difference between Lots I and III. These animals were in good condition throughout the experiment and made fairly rapid growth.

Lots V and VI, receiving the mixed supplement, were in excellent condition and grew rapidly; they showed a greater liking for their diets than did the other animals, cleaning up their allotted quantities of feed more rapidly and always seeming hungry. One animal (No. 30 in Lot VI) was an exception so far as gains and condition were concerned. At the start of the experiment it was one of the largest animals in the lot. The bulky diet, however, seemed to be unsatisfactory, as it showed little or no change in weight during the trial. Post-mortem examination showed this rabbit to be definitely abnormal. The pyloric opening of the stomach was partially blocked, causing the accumulation of a packed mass of material in the stomach that could not pass through into the intestine. The data from this animal, therefore, were discarded in the analysis of the trial.

In Lot IV the beneficial effect of the added cystine became less pronounced towards the end of the experiment. The animals in Lot II lost condition rapidly at first, and although their general condition did not improve, some gains in weight were later recorded. The animals in Lot IV did not become poor and emaciated as rapidly as those in

Lot II, but at the close of the experiment their condition was not greatly different from the animals receiving no supplement.

The data.—The details of the initial weights and gains together with the statistical analysis of the gains are given in Appendix, Table 3. For purposes of statistical analysis, the gains for rabbit No. 17 (Lot II), which died on the ninth day of the experiment, and those for rabbit No. 30 (Lot VI) found abnormal on post-mortem examination after the trial, were estimated according to the method of Yates [4]. The mean lot gains are shown in the table following:

TABLE 3. *Effect of Fertilization on Quality of Protein in Pasture Grass (mean gains)*

Lot I	*Lot II*	*Lot III*	*Lot IV*	*Lot V*	*Lot VI*
Fertilized grass	Unfertilized grass	Fertilized grass + cystine	Unfertilized grass + cystine	Fertilized grass + cystine + casein	Unfertilized grass + cystine + casein
321	25	370	70	643	553

Analysis indicated that the difference between the mean gains of the animals on fertilized herbage (Lot I) and those on unfertilized herbage (Lot II) is highly significant. The increase in mean gains of Lots III and IV over Lots I and II, respectively, as a result of the addition of cystine, however, is not significant. The addition of the mixed supplement in Lots V and VI resulted in a highly significant increase over Lots I and III and II and IV, respectively. The difference between Lots V and VI is not significant.

Summary of Results and Discussion

Fertilized v. *unfertilized herbage* (Lots I and II).—The results of this comparison support those of the previous trial, namely, that some factor or factors other than quantitative differences in total protein, energy value, fibre or minerals (Ca and P) of the rations must be responsible for the difference in their nutritive value. The chemical analyses of the diets of these two lots show no appreciable difference excepting for phosphorus. That the animals in Lot VI made highly satisfactory gains on a diet still lower in P (than that of ration of Lots I and II) is evidence that this element was not a limiting factor in this comparison.

Addition of cystine (Lots III and IV). The failure of the addition of cystine to increase significantly the nutritive value of the herbage in either series is evidence that, in the case of these pastures, cystine is not deficient, or that still other amino acids are involved with cystine in limiting the feeding-value of the herbage.

It will also be noted that cystine supplements did not alter the relative standing of the fertilized and the unfertilized grass.

Addition of cystine plus casein (Lots V and VI).—The marked increase in the growth of the rabbits as a result of the addition to their diets of the mixed amino-acid supplement is the important feature of this

experiment. It is possible, of course, that a part of this increase was due to the slightly higher content of nitrogen-free extract in these diets. This theory, however, fails entirely to account for the relatively greater increase in the unfertilized-grass as compared with the fertilized-grass diet.

When this supplement was added the difference in the nutritive values of the diets containing fertilized and unfertilized grass disappeared. It seemed evident that the addition of the mixture of the essential amino acids was responsible for this result.

It would seem, therefore, (1) that the explanation of the differences in nutritive value of the herbage from fertilized versus unfertilized pasture lies partly in their amino-acid make-up, and (2) that in the herbage from these pastures cystine alone is not the limiting factor in their nutritive value.

It is fully realized that much further work will be necessary before definite conclusions can safely be drawn. However, all three tests herein reported have been quite clear cut, and it would seem, therefore, that the findings might be used to formulate a tentative working hypothesis around which to build further studies.

The first test points strongly to the idea that different species of grasses may be markedly different in their nutritive value, even though a routine feeding-stuffs analysis does not indicate such a difference.

The second and third tests suggest that at least a part of such differences, in mixed pasture-herbage, may be traced to the protein-complex. Here, of course, there may be involved several factors that are not separately measurable in these tests. For example, it is quite possible that the preparation of the feed (i.e. grinding and mixing), which prevented the counterpart of selective grazing, may have influenced the results, especially in the case of the herbage from the untreated pasture. Observation of grazing animals has shown that there is much less tendency for selective grazing on fertilized than on unfertilized pastures. Does it follow, then, that if selection is prevented, as in these tests, we are diluting the nutritious grasses with certain others of low feeding-value, thus lowering the value of the whole diet? And hence that the effect of fertilization is more a change in botanical composition of the mixture than of change, perhaps of protein-quality, within a species?

If this be the case, then it must require but a small change to produce wide differences, as is evident from the botanical composition of the mixture fed in these tests [1, Table 6, p. 345]. The chief change noted in the above-mentioned table is that of clover replacing weeds. Will other changes in botanical composition give the same difference in feeding-value? Obviously that can be determined only by a knowledge of the nutritive properties of the pure species, studies of which are now under way as a part of this investigation.

Then there are doubtless those who would question results obtained with rabbits in so far as their applicability to farm live stock is concerned. This problem urgently needs attention, for, while not thus far shown, it may nevertheless be found that the rabbit may have a peculiarly high requirement for some nutritional substance, as, for example, the

guinea-pig for vitamin C, which does not hold for cattle or sheep. These tests are reported, therefore, not only for the comparative data which they have yielded, but also in the hope that they may stimulate similar studies by other stations from which more information on the possible usefulness of rabbits in comparative feeding studies of diets for farm ruminants may be obtained.

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APPENDIX

TABLE 1. *Timothy* v. *Reed Canary-Grass. Initial Weight, Feed Eaten, and Gains (expressed in grams)*

Lot I Reed canary-grass 100%				*Lot II* Timothy 100%				*Lot III* Reed canary-grass 95% Lactalbumin . . 5%				*Lot IV* Timothy . . 95% Lactalbumin. 5%				*Lot V* Alfalfa meal . 50% Oats . . . 40% Linseed meal 10%			
Rabbit no.	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*
6	1,430	8,160	385	7	1,385	8,430	760	31	1,375	7,810	460	12	1,500	8,005	820	11	1,750	10,285	1,355
5	1,425	8,330	105	33	1,385	7,605	670	15	1,450	7,430	165	32	1,450	8,120	735	17	1,525	7,750	935
13	1,340	7,150	210	14	1,275	8,060	620	8	1,275	7,560	300	10	1,335	7,570	685	3	1,500	9,675	1,365
27	1,200	8,220	340	24	1,250	7,715	540	4	1,275	8,950	545	9	1,330	7,585	830	26	1,475	9,960	1,525
1	1,350	8,135	225	23	1,250	8,305	735	16	1,450	7,645	235	19	1,225	7,965	1,000	21	1,425	10,200	1,615
Av.	1,349	7,999	273	..	1,309	8,023	665	..	1,365	7,879	341	..	1,368	7,849	814	..	1,535	9,574	1,359
Mean gains adjusted for differences in initial weights and feed intake . .			287·56	..	..	..	641·14	..	..	..	389·78	..	..	..	870·58	..	..	..	1,262·87

Note: Initial weights are those of test-period proper. Initial weights at beginning of preliminary period are shown in table of allotment data.

Statistical analysis by variance yields the following results:

Standard error ($D/F^{*} = 13$) = 87·24 gm.

Standard error of lot means = $87{\cdot}24/\sqrt{5}$ = 39·01 gm.

Necessary difference between means of five ($P = 0{\cdot}05$) = $39{\cdot}01 \times \sqrt{2} \times t\,(n=13)$ = 119·15.

* Three degrees of freedom for error lost through calculation from the data of two regression values (initial weight on gain and feed on gain) and one missing value.

TABLE 2. *Fertilized* v. *Unfertilized Pasture Grass. Initial Weights, Feed Eaten, and Gains (expressed in grams)*

Lot I *Fertilized grass 100%*				*Lot II* *Unfertilized grass 100%*			
Rabbit no.	*Initial weight*	*Total feed*	*Gains*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gains*
1	920	2,775	305	2	960	2,620	−245
3	910	2,765	250	4	855	2,985	−55
5	785	2,900	330	6	760	2,545	65
7	635	1,985	160	12	500	1,810	15
Av.	812·5	2,606·25	261·25	..	768·75	2,490	−55

Statistical analysis yields the following results:

Standard error (D/F = 3) = 120·2 gm.
Standard error of lot means = $120{\cdot}2/\sqrt{4} = 60{\cdot}1$ gm.
Necessary difference between lot means $P = 0{\cdot}05 = 60{\cdot}1 \times \sqrt{2} \times t\,(n=3) = 270{\cdot}4$.

TABLE 3. *Effect of Fertilization on the Quality of Protein in Pasture Grass. Initial Weight, Feed Eaten, and Gains (expressed in grams)*

Lot I	%	*Lot II*	%	*Lot III*	%	*Lot IV*	%	*Lot V*	%	*Lot VI*	%
Fertilized grass	92·6	Unfertilized grass	99	Fertilized grass	90·0	Unfertilized grass	96·0	Fertilized grass	55·50	Unfertilized grass	59·50
Oat-hulls	32·2	Salt	1	Cystine	0·4	Cystine	0·4	Casein	5·00	Casein	5·00
Sucrose	3·2			Oat-hulls	4·3	Oat-hulls	1·3	Cystine	0·13	Cystine	0·13
Salt	1·0			Sucrose	4·3	Sucrose	1·3	Oat-hulls	19·19	Oat-hulls	17·19
				Salt	1·0	Salt	1·0	Sucrose	19·18	Sucrose	17·18
								Salt	1·00	Salt	1·00

Rabbit no.	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*	*Rabbit no.*	*Initial weight*	*Total feed*	*Gain*
1	1,615	3,255	300	2	1,550	3,255	190	11	1,610	3,255	315	28	1,455	3,255	30	29	1,635	3,255	625	30	1,635	3,255	560*
18	1,450	3,255	310	16	1,435	3,255	−335	32	1,575	3,255	480	8	1,475	3,255	−110	6	1,450	3,255	645	7	1,450	3,255	545
19	1,355	3,255	245	17	1,215	3,255	15*	31	1,300	3,255	290	5	1,340	3,255	145	20	1,330	3,255	655	3	1,315	3,255	570
4	1,300	3,255	400	21	1,305	3,255	30	12	1,300	3,255	240	26	1,300	3,255	40	13	1,440	3,255	520	9	1,300	3,255	455
10	1,160	3,255	350	27	1,090	3,255	225	14	1,090	3,255	525	22	1,195	3,255	245	23	1,225	3,255	770	24	1,210	3,255	635
Av.	1,376	3,255	321	..	1,319	3,255	25	..	1,375	3,255	370	..	1,353	3,255	70	..	1,416	3,255	643	..	1,382	3,255	553

* Calculated.

Note: Initial weights shown are for test-period proper. Initial weights for preliminary period are shown in table of allotment data.

Statistical analysis by variance method yields the following results:

Standard error ($D/F\dagger = 18$) = 116·73 gm.

Standard error of lot means = $116{\cdot}73/\sqrt{5}$ = 52·205 gm.

Necessary difference between means of five to cover experimental error ($P = 0{\cdot}05$)
= $52{\cdot}205 \times \sqrt{2} \times t\,(n = 18)$ = 148·38.

† Two degrees of freedom lost through calculation of missing values.

THE COMPARATIVE DIGESTIBILITY OF ARTIFICIALLY-DRIED PASTURE HERBAGE BY SHEEP AND RABBITS

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WITH a view to simplifying and reducing the work and expense involved in digestibility trials, with special reference to pasture, consideration was given to the possibility of using rabbits in the place of ruminants, e.g. sheep or steers. Very little information appears to be available in the literature as to the digestive powers of rabbits, particularly in comparison with those of other species. Some early contributions were made to this subject by von Knieriem [2] and Weiske [3]. They determined the digestibility of cereals and feeding-cakes when fed alone to rabbits, and compared these results with those obtained by feeding the same materials, superimposed in a fodder ration, to sheep. Weiske, in one case, also fed oats alone to sheep and compared these results with those obtained with rabbits. The results in these cases indicated that the digestibilities were of the same order when determined with rabbits and with sheep. Von Knieriem [1] did determine the coefficients of digestibility of a number of species of clovers and grasses with rabbits, but, unfortunately, carried out no simultaneous comparison with ruminants. In view of work in progress and projected at Ottawa for a study of the nutritive value of pasture herbage, it was decided to carry out a comparative investigation on such material with a view to obtaining information as to the possibility of simplifying this investigation. Accordingly the tests with rabbits and sheep reported in this paper were carried out at the Rowett Research Institute.

Experimental

The material used for these studies was an artificially-dried pasture herbage, consisting of mixed grasses with some clover. It was cut in August 1934, when five weeks old, and dried in a band-drier.

The experimental animals consisted of four male rabbits and two wether sheep. Their ages, weights, breeds, and daily rations are given in Table 1.

The quantities fed were such as were readily and easily consumed by the animals. There was no refused feed. Rabbit 4, however, on several occasions during the first trial scattered his food on the floor of the metabolism cage. This was weighed and analysed and the necessary corrections made, but it was felt advisable to carry out a second trial. In the case of the remaining animals some scattering of the ration was unavoidable, but, as will be seen in Table 2, the quantities were negligible. They were, nevertheless, taken into account in calculating the coefficients of digestibility.

TABLE 1. *Experimental Animals and Daily Rations*

Animal	*Age in months*	*Weight* (kg.)	*Breed*	*Daily Ration of Herbage* (gm.)	
				Trial 1	*Trial 2*
Rabbit 1	9	2·32	English	125	..
„ 2	9	1·87	Silver Dutch	125	..
„ 3	9	2·09	Chocolate Havana	150	125
„ 4	9	2·20	English	150	125
Sheep 1	11	30·8	Orkney cross	700	..
„ 2	11	30·2	Orkney cross	700	..

TABLE 2. *Feed-Residues in Digestion Trials expressed as Percentage of Total Ration on Dry-Matter Basis*

Animal	*Residues (per cent.)*	
	Trial 1	*Trial 2*
Rabbit 1	0·67	..
„ 2	0·74	..
„ 3	0·31	0·51
„ 4	11·43	2·71
Sheep 1	1·40	..
„ 2	0·61	..

Preceding each trial, the hay was sampled and the necessary number of daily rations weighed out. The trial itself was divided into a preliminary period of ten days and a collection-period of twelve days. The collection-period was further divided into three equal sub-periods during each of which a composite sample of the faeces was prepared and analysed.

The necessary data for calculating the coefficients of digestibility are presented in Tables 4, 5, 6, and 7 in the Appendix, whilst a summary of the coefficients of digestibility is given in Table 3.

Discussion of Results

From the data given in Table 3 it will be observed that the total digestibility of the pasture herbage, as indicated by the organic-matter value, was much lower with the rabbits than with the sheep. The explanation for this seems to rest largely in the fact that the rabbits were unable to make very efficient use of the crude-fibre fraction. The average coefficient of digestibility for this constituent was 26·0 with the rabbits whereas the coefficient determined with sheep was 74·5. The rabbits also showed an appreciably lower digestibility-coefficient for the N-free extractives.

The crude protein was quite well digested by the rabbits, though the average coefficient was somewhat lower than that with sheep. It must be borne in mind, of course, that the relatively large amount of undigested crude fibre in the digestive tract of the rabbit probably caused an increase

TABLE 3. *Coefficients of Digestibility of Pasture Herbage Determined with Sheep and Rabbits*

Animal	*Dry matter*	*Organic matter*	*Nitrogen*	*Ether-extract*	*Crude fibre*	*N-free extract*
	%	%	%	%	%	%
Trial 1						
Rabbit 1	49·4	49·3	60·9	23·9	28·7	56·2
,, 2	49·8	49·5	64·3	21·5	27·0	56·6
,, 3	45·6	45·1	58·4	21·9	21·3	53·2
,, 4	48·1	48·0	60·8	22·8	26·1	55·7
Trial 2						
Rabbit 3	49·0	48·9	61·5	32·0	25·2	56·0
,, 4	50·9	50·9	63·1	32·9	27·6	57·9
Aver. for rabbits	48·8	48·6	61·5	25·8	26·0	55·9
Sheep 1	74·3	77·0	76·9	51·3	73·5	81·3
Sheep 2	74·3	77·3	76·4	52·2	75·5	81·4
Aver. for sheep	74·3	77·2	76·7	51·8	74·5	81·4

in the percentage of metabolic faecal nitrogen. Further, this fibre may have protected some otherwise digestible protein from the processes of absorption. It should not be concluded, therefore, from the data that the rabbits have less ability than the sheep to digest the proteins *per se* of the pasture herbage.

The coefficients of digestibility of the ether-extract were probably also influenced by metabolic products in the faeces. They were lower with the rabbits than with the sheep.

In general, it may be stated that, as indicated by the results with sheep, this artificially-dried pasture herbage was a highly digestible feeding-stuff. The rabbits, however, did not digest the crude fibre very readily. Largely at least, in consequence of this, the total digestibility of the herbage with this species was low in comparison with sheep. These results indicate quite clearly that in any study of the nutritive value of pasture as measured by its digestibility, it is not safe to use rabbits as experimental animals in place of sheep.

Summary and Conclusions

Digestibility trials were conducted with four rabbits and two sheep on an artificially-dried pasture herbage of five-weeks' growth.

The rabbits did not digest this herbage as well as the sheep. An important contributory cause of this was the inability of the rabbits to make efficient use of the crude-fibre fraction.

One of us (C.J.W.) desires to acknowledge his indebtedness to the Director, Sir John Orr, and Governors of the Rowett Research Institute for permission to work there for three months.

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APPENDIX

TABLE 4. *Composition of Artificially-dried Pasture Herbage*

(Dry-matter basis)

	Moisture	*Ash*	*Protein* (N × 6·25)	*Ether-extract*	*Crude fibre*	*N-free extract*
	%	%	%	%	%	%
Trial 1	10·05	9·37	20·76	5·15	21·56	43·16
Trial 2	9·07	9·27	20·93	5·11	21·33	43·36

TABLE 5. *Calculation of Coefficients of Digestibility of Rabbits in Trial 1*

(Weights in grams. Collection-period 12 days)

	Dry matter	*Organic matter*	*Nitrogen*	*Ether-fibre*	*Crude fibre*	*N-free extract*
Rabbit 1						
In feed . .	1,340	1,214	44·5	69·0	289	578
In faeces . .	678	616	17·4	52·5	206	253
Digested . .	662	598	27·1	16·5	83	325
Coefficients % .	49·4	49·3	60·9	23·9	28·7	56·2
Rabbit 2						
In feed . .	1,339	1,213	44·5	69·0	289	578
In faeces . .	672	613	15·9	54·2	211	251
Digested . .	667	600	28·6	14·8	78	327
Coefficients % .	49·8	49·5	64·3	21·5	27·0	56·6
Rabbit 3						
In feed . .	1,614	1,462	53·6	83·1	348	697
In faeces . .	878	802	22·3	64·9	274	326
Digested . .	736	660	31·3	18·2	74	371
Coefficients % .	45·6	45·1	58·4	21·9	21·3	53·2
Rabbit 4						
In feed . .	1,434	1,302	47·2	74·1	314	619
In faeces . .	744	677	18·5	57·2	232	274
Digested . .	690	625	28·7	16·9	82	345
Coefficients % .	48·1	48·0	60·8	22·8	26·1	55·7

TABLE 6. *Calculation of Coefficients of Digestibility with Rabbits. Trial 2.*

(Weights in grams. Collection-period 12 days)

	Dry matter	*Organic matter*	*Nitrogen*	*Ether-extract*	*Crude fibre*	*N-free extract*
Rabbit 3						
In feed . .	1,357	1,231	45·4	69·3	290	588
In faeces . .	692	629	17·5	47·1	217	259
Digested . .	665	602	27·9	22·2	73	329
Coefficients % .	49·0	48·9	61·5	32·0	25·2	56·0
Rabbit 4						
In feed . .	1,327	1,204	44·4	67·8	283	575
In faeces . .	651	591	16·4	45·5	205	241
Digested . .	676	613	28·0	22·3	78	334
Coefficients % .	50·9	50·9	63·1	32·9	27·6	57·9

TABLE 7. *Calculation of Coefficients of Digestibility with Sheep.*

(Weights in grams. Collection-period 12 days)

	Dry matter	*Organic matter*	*Nitrogen*	*Ether-extract*	*Crude fibre*	*N-free extract*
Sheep 1						
In feed . .	7,450	6,751	247	384	1,606	3,216
In faeces . .	1,913	1,555	57	187	426	601
Digested . .	5,537	5,196	190	197	1,180	2,615
Coefficients % .	74·3	77·0	76·9	51·3	73·5	81·3
Sheep 2						
In feed . .	7,513	6,808	250	387	1,619	3,243
In faeces . .	1,930	1,545	59	185	397	604
Digested . .	5,583	5,263	191	202	1,222	2,639
Coefficients % .	74·3	77·3	76·4	52·2	75·5	81·4

THE ROOT-SYSTEM OF THE SUGAR-CANE

Pt. I. METHODS OF STUDY

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With Plate 19

Introduction.—This journal has recently contained a series of very interesting contributions by Nutman on the root-system of *Coffea arabica* [1, 2], and it is thought that a description of the investigations on the root-system of different varieties of sugar-cane, carried out during the last three years in Mauritius, will provide an interesting comparison of the methods used and the problems to be solved in the case of two such widely differing crops as sugar-cane and coffee.

For those who are unfamiliar with the agriculture of the sugar-cane, it may be stated that the planting material (except new seedling varieties, which are grown from seed) consists of the top part of the stem, generally known as 'setts'. These setts bear rings of small dots or root-primordia just above the nodes, and at the nodes bear the buds. Two, or sometimes three, such setts are planted in holes about 6 in. deep and covered with a light layer of soil. On germination, the root-primordia develop giving rise to the 'sett-roots', and the buds sprout giving rise to the young shoots. The crop eventually obtained is called the virgin, or plant crop; in Java it is the only one reaped, the field being afterwards uprooted, but in Mauritius and in several other sugar-producing countries the stools sprout again after the virgin crop has been harvested, and give rise to a succession of ratoon-crops. Usually five or six such ratoon-crops are reaped before the field is uprooted and a virgin crop again planted.

The study of the root-system of a fast-growing crop like sugar-cane presents a multitude of problems for elucidation. The most important aspects of the subject may be summarized as follows:

1. The development of the root-system of the virgin crop from the cutting to maturity. This involves studies in the 'germination' of the cuttings; the nature, spacial distribution, and quantity of roots with age.
2. The development and nature of the root-system of ratoon-crops.
3. A survey of the root-systems of different varieties of cane. Varietal differences in the root-system are of great importance in selecting canes for particular conditions.
4. The effects of soil and of external factors in general on the nature and the distribution of roots.
5. The nature of the individual roots; formation and length of life of root-hairs; changes in the roots with age.
6. The function of the various types of roots; physiological activity in different layers; depths to which the roots absorb water and mineral salts.
7. The effects of cultivation and of fertilizer applications on root-development; possible tropic responses.

More or less bound up in these main aspects are such problems as the relationship between the root-system and aerial development and the resistance of root-systems to insect pests and to diseases in general. Resistance to insect pests is of considerable importance in Mauritius, where large areas suffer severely from the depredations of the root-eating larvae of the beetle *Phytalus smithi*, Arrow. Fundamental research on sugar-cane root-systems is of great importance for the elucidation of problems connected with the time and method of application of fertilizers; the time and value of various cultural practices; the proper distribution of varieties on the basis of their suitability for dry or waterlogged conditions; resistance to cyclones, which are common in the colony; and other problems of greater or less moment.

A review of the most important investigations carried out elsewhere on the root-system of sugar-cane has recently been published (see Bulletin No. 6, Sugar-cane Research Station, Mauritius), and it is not proposed to review previous investigations here.

Methods and Procedure

Several methods have been used for the study of certain aspects of the root-habits of sugar-cane. As some of these methods may prove of value to other investigators in this field it is proposed to describe them in some detail.

I. *Early Stages*

For the study of the 'germination' stages, i.e. from the time of planting the sett to about 3 months of age, two principal methods have been used: (*a*) the quantitative method of weighing the sett-roots and the shoot-roots (i.e. those roots arising from the young shoots as contrasted with the sett-roots originating from the sett) at intervals, accompanied by microscopic examination to determine the density of root-hairs, degree of branching, &c.; (*b*) planting the setts in specially made root-boxes containing the soil layers in the same order as they occur naturally in the field. The boxes have detachable sides, and the main framework of the box bears sheets of wire-netting in the horizontal and vertical planes. At the time of examination the sides of the box are removed and the soil washed away with a jet of water leaving the roots suspended in the netting. The root-system is then carefully examined. This method is, in essentials, similar to that used by Venkatraman in India, as subsequently modified by Hawaiian workers [3, *et seq.*].

II. *Development of the Root-system and Study of Mature Root-systems*

For the study of root-systems at various ages from 3 months to maturity, and for the survey of the varietal distribution of roots, three chief methods have been used:

(*a*) *The 'direct-examination' method of Weaver.*—This method involves digging a trench at a distance of about 8–10 in. from the stool, and as a rule long enough to include 4–5 stools. The trench is dug in the first instance to a depth of about 4 ft. and roots are laid bare, starting from the stool out-

wards. The position and course taken by every root in a specified thickness of soil (6 in.) is mapped to scale on graph paper, and in following the roots downwards the trench is deepened. In some cases it was necessary to dig the trench to a depth of 20 ft. to follow the deep roots to their termination. A chart showing the root-system in section is thus obtained, but generally a section in two directions at right-angles was taken, as it has been shown that the root-system is not always symmetrical.

(*b*) *The 'block' method.*—The author first saw this method used by W. S. Rogers at East Malling Research Station in a study of the root-system of fruit trees. Owing to the extreme thinness of sugar-cane roots as compared with the relatively thick roots forming the framework of the root-system of fruit trees, it was necessary to modify the method as previously used. The method involves the determination of the position in space of every root, and the subsequent reconstruction of the root-system in a specially-made frame. A rough indication of the spread of roots is first obtained, and a square trench is dug enclosing an area, the magnitude of which depends upon the spread of roots. This area is divided into four quarters which are termed *A*, *B*, *C*, and *D*, and each quarter is subsequently subdivided into smaller squares with 1-ft. sides. Each little square may be designated *Aa*, *Ab*, &c., to indicate its position in the large square *A*, or *Ba*, *Bb*, &c., its position in the large square *B*. By means of a variety of instruments, such as little hand-picks, trowels, prospector's picks, &c., each root in one of the small squares is laid bare to a depth of 6 in. The direction and position of each root is marked to scale on a chart, and records of the depths of the end nearer the stool and the end remote from the stool are taken for each root. The course of the roots in space is thus accurately known; each root is given a nomenclature, such as Aa_1, Bd_3, which is noted in the chart, and a label bearing this nomenclature is tied to it. Each square foot is dealt with thus to a depth of 6 in., until the whole root-system has been excavated to the same depth. The next 6 in. are then dealt with in the same way, and similarly the following layers, until the whole root-system has been excavated, charted, and labelled. A large frame of about $8 \times 8 \times 6$ ft. is then built with cross wires at intervals of 6 in. The root-system is reconstructed in this frame, each root being placed in its correct position. The reconstructed root-system, which is thus identical in position with that occupied in the soil, can be studied and photographed.

In the later investigations the method was modified in detail so that areas larger than 1 sq. ft. could be dealt with at a time; these areas, being narrow sectors reaching to the stool, made it unnecessary to cut the roots frequently and then tie them together afterwards. This is probably the best method that is likely to be worked out for the detailed investigation of the distribution of sugar-cane roots, not only because of the convincing reconstructed system obtained at the end of the work, but because of the wealth of detailed information derived in the actual excavation. It is, however, an extremely long and tedious method, and unless adequate funds and labour are available its execution is impracticable. For young root-systems, and for those which are very superficial, the method does not take so long, and has advantages over all other methods.

(*c*) *The 'successive-section' method.*—This method is intermediate between the 'direct-examination' method and the 'block' method. It involves working a trench to a depth of 1 ft. at a distance of about 8 ft. from the stool, the actual distance depending upon the length of the longest roots. The trench is sufficiently long to cover about 4 stools. The side of the trench nearest the stools is worked towards the stool for a few inches with hand-picks, and all the roots entering into the trench are marked to scale on graph paper. The trench is then widened to 2 ft. and deepened to 2 ft., and the roots emerging into the trench are again plotted. The trench is thus progressively widened by successive foot-widths, the depth being increased by 1 ft. for each 1 ft. increase in width. The diagrams (Fig. 1) explain the method used.

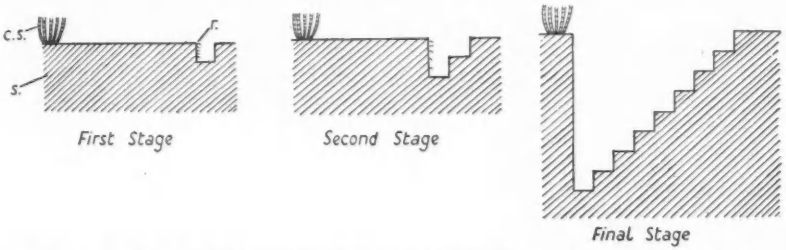

FIG. 1. Illustrating the Investigation of the Sugar-cane Root-system by the 'Successive Section' Method. *c.s.*=cane stool; *r.*=roots; *s.*=soil. Scale $\frac{1}{8}$ in.=1 ft.

It will be seen that the final stage is equivalent to the section obtained in the direct examination method. If the roots penetrated more than 8 ft., the trench was deepened until the termination of the roots was reached. This method thus amounts to the examination of one-half of the complete root-system. It tends to have a quantitative value in that the number of roots at varying distances from the stool and at varying depths is obtained. From the charts a mental picture of one-half of the root-system may be constructed. The method, although not as detailed as the block method, gives considerably more information than the 'direct-examination' method.

III. *Special Methods*

For the study of particular problems connected with the root-habits of sugar-cane certain special methods have been used.

(*a*) *Study of individual root-growth, and changes in the roots with age.*—For the study of individual roots of different varieties and their behaviour special root-boxes were used. These root-boxes were large-scale editions of the boxes with glass sides that are used in elementary plant physiology for studying the growth of bean roots, contractile roots, &c. The boxes were strongly built and measured $3 \times 3 \times 3$ ft. One side was made of glass, placed at an angle of about 30° to the vertical, and marked in square centimetres. The roots grew against the glass and were marked daily to scale on graph paper, being in complete darkness except during the daily examination.

Owing to the unnatural conditions in such boxes, in later experiments canes were planted in the field, and a long trench was dug at a distance of 2 ft. from the stools. Glass plates marked in square centimetres were fixed on the side of the trench, and the roots were observed in the same manner as in the boxes. By inserting long glass tubes filled with various fertilizers well into the soil, alongside the glass, it was possible to determine whether the fertilizer had a chemotropic action or not. The time during which the roots bore root-hairs could also be determined, and also the daily growth in length of the roots. This method of observing the growth of roots has also been extensively used by Rogers at East Malling Research Station.

(*b*) *Study of the superficial roots of ratoon-crops.*—Since in the ratoon-crops only the roots in the first 8 in. of soil are markedly affected by manuring and cultivating operations, a special study of the roots in this layer was made and the effect of cultivation on root-growth determined. For this study, pegs were placed in the ground to hold the roots in their correct position, and the soil was removed by means of a water-jet. All the main roots in the inter-line and between the stools in the row were plotted to scale on graph paper, a distinction being made between the older roots and the new white roots.

(*c*) *Studies on the functions of sugar-cane roots.*—Considerable light has been thrown on the functions of the different types of sugar-cane roots by making use of the well-known phenomenon of root-exudation. Trenches were dug in the region previously occupied by the stools, the roots outside the trench being left undisturbed in the soil. The soil was removed from the cut ends of the roots for a distance of about 6 in., and the cut ends were washed with formalin and thereafter with distilled water. Tubes were placed to receive the liquid exuded by the cut ends of the roots, the latter being fixed in position by plugs of cotton-wool. The tubes were held by wire holders, the free ends of which were forced into the soil. By collecting and analysing liquid exuded by roots at various depths, considerable information on the absorbing capacity of the roots was obtained.

IV. *Nature of the Sugar-cane Root-system*

To understand the true nature of the mature root-system of the sugar-cane, it is necessary to trace briefly its development. As has been stated above, the root-primordia on the sett 'germinate' under favourable conditions and give rise to the 'sett-roots', which are thin, much-branched fibrous roots passing laterally outwards to a distance of $1\frac{1}{2}$ to 2 ft. Following protrusion of the sett roots, the buds on the sett swell and sprout, giving rise to the young shoots. The root-primordia at the very base of the young shoot are much larger than those borne on the sett, and also much larger than those borne later on the young shoot. These large root-primordia 'germinate' to give rise to thick white roots, which Venkatraman [3] has called 'shoot-roots'. The shoot-roots in the main pass downwards into the subsoil, and are not so profusely branched as the sett-roots. As more and more nodes are laid down in the growth of the young shoot, more root-primordia germinate, those nearer the soil

surface giving rise to roots which generally pass laterally outwards and form the framework of the superficial root-system of the cane.

The sett-roots are temporary, they soon die and decay, and, in general, the number of sett-roots left by the time the cane is 3 months old is negligible. There is often a tendency for the roots to be influenced in their line of growth by the direction which the bud on the sett faced when planted. Setts also often show a marked polarity, the roots germinating first on the basal end of the cutting, and shoots at the apical end. Roots developed from primordia on that side of the cutting which happens to be uppermost often become aborted and shrivel up, whereas those borne on the underside of the cutting make vigorous growth. The sequence of root-development described for the young shoot borne on the cutting is followed later by the daughter shoots and 'babas' borne on the rhizomes. Each of these has its shoot-roots at the base, forming thinner roots from nodes higher up the stem. The term 'shoot-roots', which is useful to contrast these roots with sett-roots, loses its significance when the sett-roots are no longer present, and all the roots are shoot-roots. We have therefore termed these roots 'buttress-roots', for reasons which will be given later. Since each new shoot that appears in the stool bears its buttress-roots, new shoots being formed for considerable periods, and since these buttress-roots persist for several months, they form a characteristic feature of the sugar-cane root-system at all times. The superficial roots which are produced from primordia formed later are much thinner than the buttress-roots, and, as their name implies, are located for their whole length in the surface-soil. In addition to the superficial roots and the buttress-roots, there is a third class of roots which in many respects resembles superficial roots, but turn downwards and penetrate the soil often to very profound depths. These roots often become associated in the form of strands or ropes, and have therefore been termed 'rope-systems'. They do not appear to arise from any distinctive primordia in the stool, as do the buttress-roots.

During our investigations over 200 root-systems of sugar-cane belonging to over forty different varieties were investigated in detail, and as the three types of roots distinguished above were found to be present in varying degrees of development in all the sugar-cane varieties studied, they will now be described in detail.

1. *The superficial absorbing roots.*—As has been stated, these roots originate from root-primordia situated at some distance from the base of the rhizomes. As they pass outwards from the stool they often become even more superficial; arising at the stool at a depth of 6–9 in., they terminate as a rule only a few inches below the soil surface. When they are first formed they grow away vigorously from the stool and very seldom branch. At this time they are white in colour, sometimes tinged with pink. While the root is still growing, the older part of it near the stool becomes first yellow, then brown, and when growth is complete the brown colour progresses along the root to the tip. Prolific branching of the root occurs when the growth in length is complete. The branches are fibrous and at first white, later becoming brown like their parent root. The branches thereafter bear branches of the second order, which

rarely bear branches of the third order and hardly ever branches of higher order than the third. These branch-rootlets are very densely covered with root-hairs, the superficial roots thus exposing a much increased area for absorption.

The main roots become much darker with age and eventually are almost black. The old superficial roots show another interesting feature in that they often become ribbed, assuming an appearance similar to the shoots of switch plants. Sections showed that this ribbed appearance was due to the collapse of cortical cells at some points, the hypodermal layers thereafter caving in at these points. Even when this occurs the vascular cylinder still serves as a conducting channel from the living rootlets, borne towards the end of the root, to the remaining organs of the stool. The length of the superficial roots varies: maximum lengths of 12–14 ft. were recorded in the variety Uba, and generally the longer surface-roots are 6–8 ft.; there are also several roots 2–6 ft. long. These roots form the major part of the surface system. In addition to these, however, there is later a slight addition to the surface-system caused by the germination of root-primordia at or up to an inch below the soil surface. The part of the cane on which these root-primordia are borne resembles the sett, and the roots which are formed from these primordia in many respects resemble sett-roots. They are formed only when the stool is well grown and the root-system nearly mature. Owing to their superficial origin they can be formed only when the moisture conditions are particularly favourable. They remain superficial for the whole of their length, often being only a fraction of an inch below the soil surface, are generally very short (6–18 in.) and bear a large number of fibrous branches. Owing to the quick drying out of the surface soil ($\frac{1}{2}$–1 in.) in which they occur, together with occasional harmful temperatures, they do not bear many root-hairs, and that they are of little importance to the stool is shown by the fact that they do not exude any liquid even when moisture is abundant.

It has been shown that under moist conditions the main superficial system supplies the stool with large quantities of water and with most of its mineral substances, but under conditions of drought absorption by the superficial roots is rendered almost impossible, and in order to survive the stool has to rely on the deeper roots. Typical superficial roots are shown in Fig. 2 (Plate 19).

2. *The buttress-roots.*—These roots, though in spacial distribution midway between the superficial system and the system of deep roots, are generally the first to be formed on the developing shoots. In appearance and direction of growth they remind one of stilts, except that they are underground for the whole of their length. When young they are white and succulent, and grow at a faster rate than the superficial roots. They pass outwards and downwards at an angle of 45–60°, although occasionally a few pass vertically downwards. Thus they soon enter the subsoil, and they never radically change their direction of growth. When young and actively growing, they bear a profusion of root-hairs, but when mature, root-hairs are only present in a region just behind the wax-like tip. The root acquires an orange colour as it matures, which after

considerable time may deepen to brown, but it never reaches the depth of colour of the superficial roots. When growth is active, the white wax-like root tip may be 6 in. long, with a sharply tapering point. We have actually observed buttress-roots growing at a rate of 8 cm. in 24 hours. When growth ceases, the tip becomes blunt and rounded and the orange coloration of the older part progresses to the tip. The buttress-roots are often found to be considerably distorted and flattened in various planes, so that the longer width may be from 5 to 10 times the shorter width. There is little doubt that they adjust their growth in this way in passing through a dry subsoil: the distortion does not appear to be due to subsequent crushing of the roots, after they have developed, by the stresses in the soil. This is confirmed by sections showing a vascular cylinder surrounded by large succulent cortical cells, which are longer and more numerous in the longer diameter, but show no crushing. When the activity of longitudinal growth of the buttress-roots has abated somewhat, they, like the superficial roots, give off branches. These branches are longer and thicker than the branches borne by the superficial roots and more like their parent roots in appearance. In the subsoil, where these branches are produced, rocks are generally numerous in Mauritius, and one often finds these branches growing along the surface of the boulders. When this happens branching is greater, but the branches are still fairly thick and flattened and never have a fibrous appearance. Sometimes they pass through the soft crust of the rock. Buttress-roots grow to a length of 2–5 ft., depending upon the variety and the conditions of growth. They do not expose nearly so large a surface to the soil as do the superficial roots. It is obvious from their direction of growth, the nature of their branching, and their localization in the subsoil, which is poor in mineral nutrients, that in the main they are anchoring roots, though they undoubtedly absorb to some degree. They may also act to some degree as storage organs, since the large succulent cells of the cortex contain considerable quantities of sugars and other organic materials. Their average breaking stress is about 3 kg., a value which is about double that of the main superficial roots. Buttress-roots are shown in Fig. 3.

3. *The rope-system and other deep roots.*—It has been found impossible to correlate the type of roots included in this class with their point of origin in the stool. Sometimes they arise from horizontally-growing rhizomes, and sometimes from rhizomes which grow up more or less vertically and bear the aerial culms. Intermixed with them, as regards origin, are roots which grow laterally outwards and upwards and form the main superficial roots. There may be a physiological difference between them and the superficial roots which enables them to respond to gravity in the normal way. If so, this difference does not appear to be connected with their point of origin in the stool, nor with the nature of the primordia from which they arise. Once these roots penetrate the subsoil they become very different in external appearance from the superficial roots. They are thin, but white, grow vigorously when young, and the growing tip remains white when the older parts of the root darken to become eventually almost jet black. The older roots of this class are characterized by their thin, wiry, and dark appearance; they

bear very few branches when they follow an individual course through the subsoil; but most often they do not follow an individual course, several roots originating at points often widely distant from each other in the stool become associated and the whole group passes down together as an entity. There may be only four or five such roots in the strand near the stool, but lower down at depths of 5–6 ft. the strand may contain

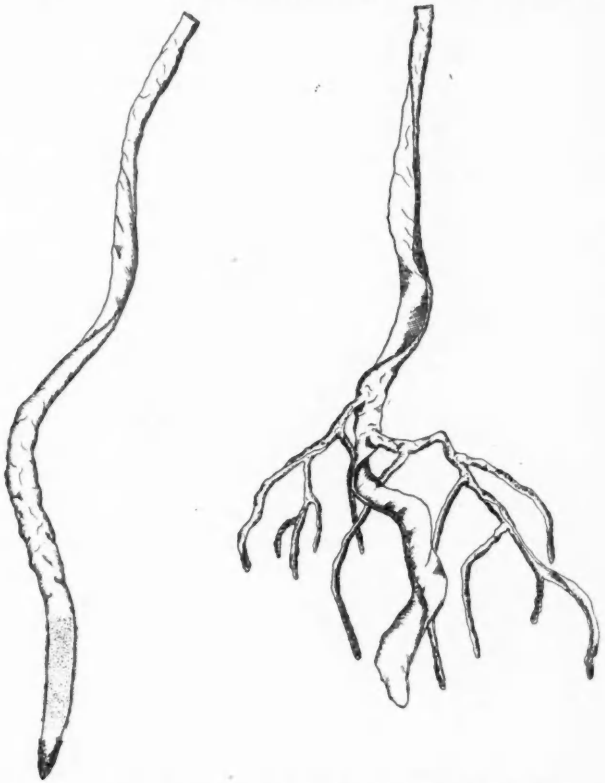

FIG. 3. Buttress-roots; on the left young unbranched root, on the right older branched root, showing distortions.

15–20 roots. The addition to the strand is sometimes due to individual roots of this class happening to grow into contact with a strand and thereafter following the same course. More often, however, it is due to roots in the strand branching to form secondaries of almost the same order of magnitude as the parent root, these branches thereafter entering into the strand entity. In addition to this type of branching, another type of branching occurs in the roots of the rope-system that leads to the formation of short roots about $\frac{1}{2}$–1 cm. in length. These short rootlets also bear root-hairs, and in practically all cases some of the main roots of the rope, when dug up, were found to be still white and growing at

the tips. The individual roots of the rope, as might be expected, do not all terminate at the same point. These rope-systems are much more strongly developed in canes having wild blood than in the noble tropical canes (*Saccharum officinarum*). In some cases, particularly Uba (*Saccharum sinense*), and seedlings of the cross POJ. 2878 × Uba Marot, they descend to depths of 15–20 ft. Rope-systems can withstand remarkably high stresses in their natural condition; a good one will support a weight of 12 kg. The remarkable behaviour of the roots in forming such rope-systems is difficult to understand, but the following explanation appears to be reasonable. The deep subsoils of Mauritius are poorly aerated, and when a channel is formed by a root, other roots follow this channel owing to the better aeration. With the inclusion of more roots, aeration is further improved. The little rootlets do not grow outwards because of lack of oxygen, and therefore curl round the parent roots of the rope. This is confirmed by the fact that when roots similar to those associated in ropes, follow an individual course through the deep subsoil they seldom bear any branches. There appears to be some repellent factor in the subsoil, which is most likely lack of oxygen but may be some other toxic factor. The latter possibility is supported by the fact that planters in general regard the subsoil of Mauritius as being particularly toxic, and for that reason do not resort to deep ploughing, the bringing of subsoil to the surface having been shown to depress yields. There is certainly a high concentration of alkali chlorides in the deeper subsoil. Although the rope-systems, whatever the cause of their peculiar growth, are so well suited for anchorage, they do not seem to be so important for this function as the superficial and, particularly, the buttress-roots. Varieties which have a poorly-developed superficial and buttress system are often blown down by high winds in spite of vigorous rope-system formation. Rope-systems are capable of very vigorous absorption, particularly because they descend to depths of soil which are moist even in times of extreme drought. Under such conditions the stool is dependent upon the deeper buttress-roots and rope-systems for its supply of water. A typical rope-system is shown in Fig. 4.

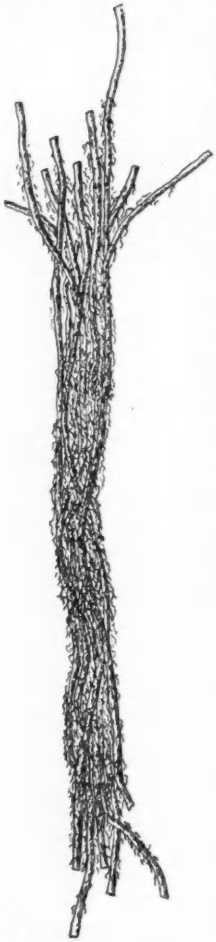

FIG. 4. Part of a Rope-system of Sugar-cane.

Summary

The root-system of the sugar-cane shows considerable variation, depending on the variety of cane, but in practically all varieties it is made

up in the main of three classes of roots; the superficial roots, the buttress-roots, and the deep roots mostly associated as rope-systems.

A good root-system is one which shows adequate development of each of the three root-types; relatively few of the cultivated varieties have such a system.

In most of the noble canes, the surface-system is well developed, and sometimes the buttress-system; but the rope-systems are very rudimentary. In some cases buttress- and rope-systems are adequately developed, but the superficial system is weak.

Fig. 5 gives a picture of the orientation of the root-types and some idea of the way in which they compose the mature root-system.

It is hoped to give a description of the more representative types of sugar-cane root-systems in a subsequent paper.

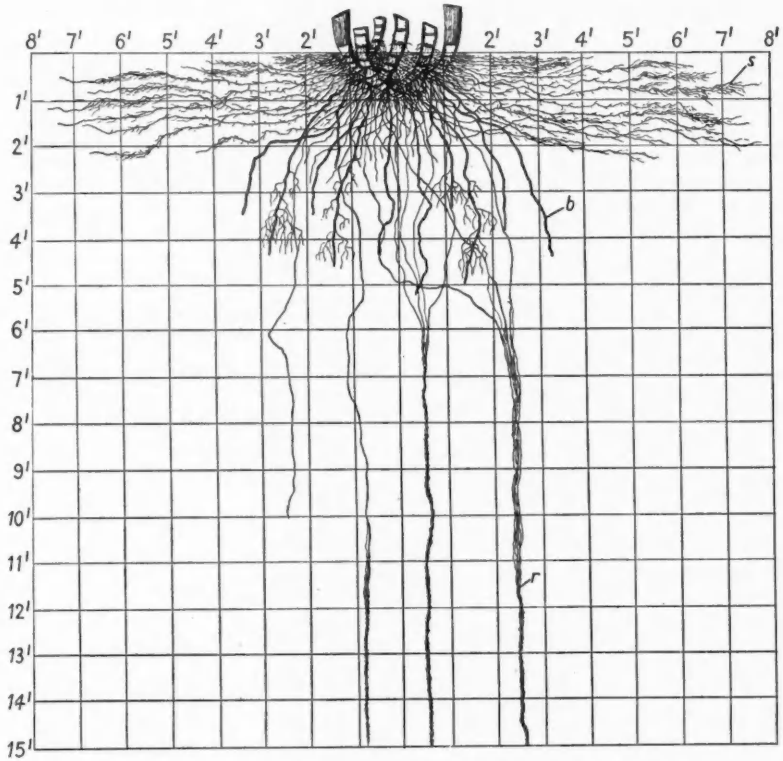

FIG. 5. Root-system of Sugar-cane showing orientation of Root-types. *s*=Superficial roots; *b*=Buttress-roots; *r*=Rope-systems.

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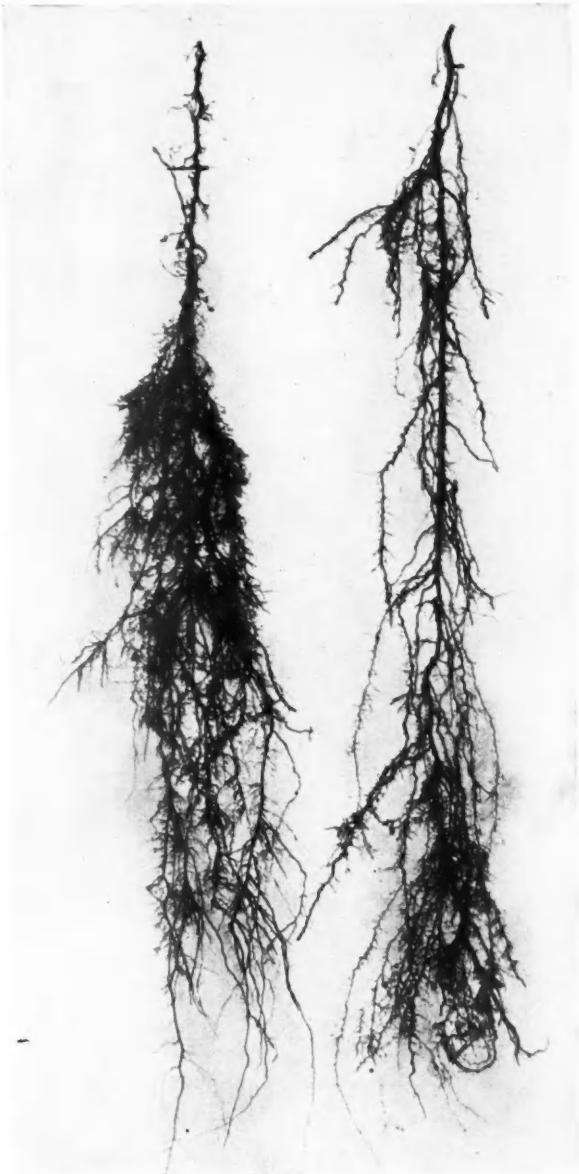

FIG. 2. Typical superficial roots of sugar-cane

MINERALS IN RELATION TO DISEASE OF THE LARGER DOMESTICATED ANIMALS

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Introductory.—The purpose of this article is to survey the more important disorders associated with metabolism of the mineral constituents of a ration, but in doing so it is impossible to avoid incidental reference to other constituents, such as vitamins, which may influence the utilization of dietary minerals, or to factors such as endocrine secretions which may affect the balance of minerals within the tissues of the animal itself. It is not always a straightforward matter to decide when a disease is due to simple mineral deficiency and when it is due to faulty operation of the physiological mechanisms for utilizing available minerals; and since the same pathological picture may result from apparently different causes, whilst different diseases may appear to arise from the same cause, it is best to consider the subject from the standpoint of animal physiology rather than from that of agricultural chemistry.

For example, the bone-disease rickets may arise in a grazing calf under a tropical sun as a result of phosphorus-deficiency in the pasture, but in a slum child arise from insufficient sunlight on a diet adequate in phosphorus—and then be curable by administration of cod-liver oil. The disease is the same in both cases but the cause is different. Conversely, if a cow and a horse be fed on a ration in which the roughage is cut down to a minimum and the concentrates unduly raised by a heavy supplement of cereals and bran, in such a way as to bring the ratio of calcium to phosphorus, expressed as $CaO : P_2O_5$, to about 1 : 3, the horse [1] will gradually develop 'osteodystrophia fibrosa' (osteofibrosis), a disorder histologically similar to Recklinghausen's Disease in man—a disease not usually associated with dietary régime at all but with tumours in the parathyroid glands. On a similar ration the cow may pass unscathed [2], but if the calcium-phosphorus ratio be widened still further skeletal disease also appears [3], but it is not osteofibrosis; it is osteoporosis, a pathologically different condition [1] which will be discussed presently.

In the progress towards the newer knowledge of nutrition built up over the last quarter of a century it is natural that the physiologist and the biochemist, working with synthetic diets and small laboratory animals in the spirit of pure scientific inquiry, should have led the way, and at first there was a natural tendency to assume that conclusions based upon experimental work on guinea-pigs and rats could be carried over to the economically important domesticated animals without further ado. But it was soon realized that each species of animal must be considered separately with reference to its own physiological peculiarities and its own mode of life. This is particularly noticeable with regard to exogenous requirements of vitamins, i.e. the quantities of the different known vitamins which must actually be present in the

food. Although the vitamin requirements of the bovine cannot be altogether ignored, young heifers have been brought from a live-weight of 300 lb. to a weight of 1,200 lb. [2] on a ration so low in all vitamins that it would induce scurvy in the guinea-pig (vitamin C), polyneuritis in the pigeon (vitamin B), xerophthalmia and nutritional failure (vitamin A) in the white rat, and rickets or osteomalacia (vitamin D) in any young animals insufficiently exposed to sunlight. The vitamin requirements of different farm animals vary considerably according to species and environmental conditions, but to continue discussion in that direction would go beyond the scope of the present paper. Suffice it for the moment to say that vitamin-deficiency diseases are less important in the larger animals than in man.

Returning to minerals, calcium and phosphorus may be considered together since both are involved in skeletal disorders. Magnesium, iron, copper, iodine, and fluorine may then be taken in order, with brief final reference to sodium, potassium, and chlorine.

Calcium and Phosphorus

At the outset two types of disease associated with calcium metabolism must be distinguished, one occurring as the result of deficiency of essential dietary constituents, and the other occurring as the result of failure of the animal to keep the minerals in its blood between healthy limits. The former may be termed 'aphosphorosis' (phosphorus-deficiency disease), or 'acalcicosis' (calcium-deficiency disease), or 'avitaminosis' (vitamin-deficiency disease) as the case may be, the word in each case signifying a cause. For low blood calcium the word 'hypocalcaemia' is used, and 'hypomineralaemia' would be a general word signifying low blood minerals without specifying any particular element or suggesting any particular cause.

Since considerable confusion exists in some quarters between low mineral-content of the blood and low mineral-content of the food, it should be explained that although the two may be related there is no necessary connexion at all. For example, if a maiden heifer is fed on a ration low both in phosphorus and in calcium, the inorganic phosphate of the blood plasma falls quite rapidly, and finally to a very low level, whilst the calcium tends to be arrested at a fairly definite lower physiological limit. After a year or so the plasma phosphate may have fallen from a normal of about 5 mg. p.c. (milligrams per 100 c.c.) even down to 1 mg. p.c., whereas the plasma calcium may have fallen only from 10 mg. p.c. to 8 mg. p.c.—a fall of 80 per cent. in one case and only 20 per cent. in the other. On the other hand, on a ration rich in both elements the blood calcium of a cow may drop quite unexpectedly from 10 mg. p.c. to 3 mg. p.c. within 24 hours of calving (milk fever) without noteworthy change in blood phosphorus.

The reason for this is that the level of plasma calcium is under the influence of a rigorous physiological controlling mechanism whilst the level of plasma phosphate is not—or at least not to the same extent. Hence although 'hypophosphataemia' is characteristic of phosphorus-

deficiency in the food, one cannot argue that 'hypocalcaemia' indicates calcium-deficiency.

In the case of calcium the physiological controlling mechanism is 'nervous endocrine' in nature, the word endocrine being used to refer to certain glandular structures which secrete active principles directly into the blood-stream and not through ducts. Such glands operate in association with the sympathetic nervous system and co-operate with the organs of storage, of absorption, and of excretion to form complex regulatory mechanisms all of which are not yet understood. Of the glands concerned in regulating the level of blood calcium, the parathyroids, small structures in the neck in the neighbourhood of the larynx, are the most important. If these are removed experimentally the blood calcium at once falls but can be restored by injecting parathyroid extract. So long as they are in good working order they, in co-operation with the nervous system, bones, intestines, and kidneys, keep the blood calcium between narrow limits (usually 8 to 11 mg. p.c.), so that even when the food contains too little the level is kept up by calling on skeletal reserves. This can go on even when the skeleton has been tapped to the point of disease.

Before proceeding to a consideration of skeletal diseases caused by mineral-deficiency a few paragraphs may be devoted to hypocalcaemic disorders.

Hypocalcaemia.—For a general understanding of the problem the reader may be referred to the recent lengthy review [4] of Schmidt and Greenberg on 'Occurrence, Transport, and Regulation of Calcium, Magnesium, and Phosphorus in the Animal Organism', and to Carlström's paper [5] on 'Hypocalcaemic Morbid Conditions in Domestic Animals'. The commonest example is the well-known 'milk fever', a disorder far commoner amongst civilized dairy cows bred for high milk-production and fed on mineral-rich rations than it is amongst low-yielding cows reared under ranching conditions even in areas poor in minerals. The typical disease occurs just after calving, comes on suddenly, and may terminate in coma (complete unconsciousness). It is therefore often termed 'puerperal paralysis', and under this name has been described in animals other than the cow, e.g. in the ewe, where it is also termed 'lambing sickness'.

The common fall in plasma calcium is from the normal value of about 10 mg. p.c. down to half or less (range 7 mg. p.c. to 2 mg. p.c.) and is quite sudden. Any factor which temporarily raises the calcium level promptly alleviates the symptoms, and the animal then usually makes an uneventful recovery. This may be accomplished by distension of the udder, as in the well-known curative treatment by inflation with air, or by injection of a soluble calcium salt into a vein or under the skin. The salt generally used is calcium gluconate or the more soluble borogluconate [6], because they are less irritant than the chloride. The small amount of calcium injected disappears from the blood in a few hours, so that it is not a question of supplying calcium needed by the body but merely of correcting the hypocalcaemia for the moment. Nature does the rest. In udder-inflation the older view was that damming back the

milk flow stopped the drain of calcium from the blood, but the observations of Montgomerie [7] on equine hypocalcaemia, in which symptoms were alleviated by injection of air into the subcutaneous tissues, suggest that nerve-stimulation plays a part.

All the evidence on causation points to a temporary disturbance of the 'nervous endocrine' controlling mechanism described above, and the fact that even in normal calving of dairy cows distinct changes in blood calcium, magnesium, and inorganic phosphate occur at the time of parturition [8, 9] suggests that the hypocalcaemia of puerperal paralysis is only a pathological exaggeration of normal physiological changes. Just after calving there is an enormous increase in calcium metabolism and this has to be met by increased absorption from the food. The increased demand is quite sudden, and to tide over the period until a new balance is struck between rate of absorption and rate of elimination the reserves of the skeleton are mobilized. When it is considered that the blood has to carry the calcium to the udder but that a single gallon of milk or half a gallon of colostrum contains more calcium than is present in the total blood-stream at any given moment, it will be obvious that lactation involves suddenly increased effort upon the part of the physiological controlling mechanism which keeps up the calcium level of the plasma. Normally the response is immediate and apart from a small temporary downward swing of blood calcium, followed by a compensatory swing in the opposite direction a few days later, the mechanism performs its task. The theory is that if it lags behind in its response, the blood calcium drops too far and symptoms of so-called milk fever appear (tetany leading to coma). If the hypocalcaemia is rectified by treatment the physiological mechanism apparently gets a chance of reasserting its control. The response to a single injection of a calcium salt is often spectacular; a comatose cow may rise and behave almost normally half an hour after artificial restoration of the balance of blood minerals by direct introduction of a quantity of calcium trifling in comparison with the enormous mobilizable reserves of the skeleton—which, it is assumed, could not be called up fast enough because of temporary failure of the controlling mechanism.

Skeletal disorders.—Not so long ago the skeleton was regarded mainly as a supporting framework which sheltered the active blood-forming red marrow and to which other tissues such as the muscles were attached. It is now known, however, that the hard bone is itself an actively metabolizing tissue, which undergoes continual changes right throughout life, and that the skeleton is the great nutritional reservoir for the important minerals calcium and phosphorus, and probably also for magnesium. The response of the skeleton to demands from the blood is rapid, and the extent to which it can suffer resorption before failing in its structural functions is very great.

Osteoporosis.—The organic matter of bone (ossein) is impregnated with complex earthy salts which confer strength and rigidity. The basis of these is calcium phosphate, but since the elements calcium and phosphorus are necessary for other physiological purposes, the skeleton is drawn upon whenever they are not being absorbed from the digesting

food in amount sufficient for the organism as a whole. It is not a matter of 'leaching out' of minerals but of actual break-down of bone, the portions least needed for structural purposes being resorbed first, e.g. the trabeculae and inner lamellae of the long bones. The skeleton thus becomes lighter and more porous, and to this condition, if at all pronounced, the term 'osteoporosis' is applied. When more minerals are absorbed from the food than are needed for general physiological requirements the balance is restored, fresh bone is laid down, and the skeleton reaches its maximum weight and compactness.

With a normal domesticated animal, not specially bred for high production and on a ration containing sufficient calcium and phosphorus, the nutritional function of bone as a mineral reservoir is little utilized, but in a state of nature where the natural food may suffer seasonal variations in mineral-content it may come into prominence—as on the phosphorus-deficient pastures of South Africa, Australia, and elsewhere [10]. In the modern high-yielding dairy cow it may also play an important if not obvious role, even when the ration contains abundance of minerals. In many cases breeding for high production has evolved an animal which may have an udder capable of producing milk, rich in calcium and phosphorus, faster than its intestinal walls can absorb these elements into the blood-stream from the digesting food in the lumen of the gut, so that it 'draws upon its convenient skeletal bank however high its dietary income may be' [10]. Meigs and his co-workers state that the total calcium loss of a cow usually does not exceed 20 per cent. of its total skeletal supply, and as a rule there is no serious interference with the milk yield until the losses exceed this figure; but such an animal is nevertheless almost pathological, oscillating between compact bone at the end of the dry period and a mildly porotic framework at the height of lactation. The process of bone-resorption, however, rarely proceeds to the danger-point, so that Theiler, in his consideration of the 'Osteodystrophic Diseases of the Domesticated Animals' [1], does not regard osteoporosis as a disease in itself so much as a 'stage in the evolution of some disease the last phases of which may not always be reached'. In extreme cases, however, so much bone may be removed that the skeleton becomes fragile, e.g. in the records of Becker, Neal, and Shealy [3] a cow averaged 6,338 lb. of milk in eleven consecutive lactations and then broke her pelvis in three places.

Osteomalacia and rickets.—If for any cause a skeleton becomes weakened by bone-resorption it usually attempts to repair the damage by laying down osteoid tissue (organic matrix) in preparation for subsequent calcification (deposition of minerals), but if it is unable to complete the process the bone is softer and more easily bent. To this condition of excessive uncalcified osteoid tissue the technical term 'osteomalacia' is applied. If the bone is still growing, the epiphyses, or terminal portions separated from the long bones by cartilage in early life (but later becoming part of the larger bones), are affected and the stresses on the proliferating cartilage give rise to the well-known distortions characteristic of rickets. But there is no fundamental difference; whether the failure to calcify osteoid tissue is manifested as rickets

or as osteomalacia simply depends upon the age of the animal at the time the causal factors operate. The pathologist groups both diseases under the term 'osteodystrophia malacia', and in animals which are born with a well-developed skeleton the bone picture may be a mixed one, e.g. in the calf which may show mixed rickets and osteomalacia, as compared with the human infant which shows the more typical histological picture of rickets. A detailed description of the pathology of these diseases will be found in the article by Theiler already referred to [1].

The causal factors may be deficiency of calcium, or of phosphorus, or of vitamin D, or of any combination of these. All three are necessary for normal bone metabolism, although some writers [11] maintain that calcium is necessary for formation of osteoid tissue, and hence that osteomalacia is characteristic of aphosphorosis and avitaminosis, whilst straight acalcicosis is manifested typically as simple resorption or osteoporosis.

If either calcium or phosphorus is missing it is obvious that calcium phosphate cannot be deposited. The part played by vitamin D is not quite clear, but in some way it controls absorption of calcium by the intestine and consequent mineralization of osteoid tissue. It either has to be present in the food as such or in the form of precursors which the body can use to manufacture ergosterol, a substance which can be converted into vitamin D by the action of sunlight on the skin. Hence if vitamin D is not present as such in sufficient amount in the food, the absence of sufficient sunlight may become the determining factor in the causation of rickets. In children the cause of rickets is vitamin-deficiency, often associated with insufficient dietary calcium. The value of cod-liver oil in preventing and curing rickets is due to the fact that this oil is rich in vitamin D and that with abundance of this vitamin whatever calcium is in the food is better utilized.

With grazing animals, however, the sunlight to which they are exposed is sufficient to activate the vitamin precursors they synthesize from the food, and osteomalacia and rickets do not occur naturally as a D-avitaminosis. They do, however, occur on a wide scale in different parts of the world as an aphosphorosis, wherever the natural pasture is deficient in phosphorus. The article by Theiler and Green [10] on 'Aphosphorosis in Ruminants' reviews the world position in this respect, and also deals with indirect economic consequences of phosphorus-deficiency. The 'styfsiekte' of South Africa, the 'cripples' of Australia, and the 'knochenweiche' of central Europe are all cattle diseases which should be called 'bovine osteomalacia' and are due to phosphorus-deficiency. Aphosphorosis is also common in sheep and passes under various local names such as 'osseous cachexia'. As indirect consequences of phosphorus-deficiency, not so acute as to lead to pronounced osteomalacia itself, may be mentioned retardation of growth, protective cessation of ovulation leading to reduced fertility, production of pathologically fine wool-fibre in the case of sheep (incidentally higher priced per lb. on the wool market), and osteophagia (bone-chewing) or depraved appetite leading to ingestion of material which the normal herbivore

would shun. If carcase material, common under ranching conditions (animals dying from other causes and not buried, wild game, rabbits exterminated by poison), happens to become infected with the toxicogenic saprophyte *Clostridrium botulinum* in the course of putrefaction, it may become so toxic that a few ounces of skeletal debris is fatal to an adult bovine; acute fatal botulism ('lamsiekte' in South Africa, 'bulbar paralysis' in Australia) then appears as a sequel to osteophagia, and may be obviated either by eliminating the carcase debris itself, or by correcting the depraved appetite by phosphatic supplements. Such additional nutritional phosphorus at the same time corrects the hypophosphataemia (low blood phosphorus), permits normal growth and reproduction, and, of course, eliminates the osteomalacia characteristic of extreme aphosphorosis.

Theoretically, skeletal disease could also occur as an 'acalcicosis', but since in the leafy parts of plants calcium usually preponderates over phosphorus, and minimum physiological requirements for the latter elements are higher, it does not appear in grazing animals from that cause.

In Great Britain even the poor pastures are generally sufficiently rich in phosphorus and calcium, although low by comparison with the best pastures, so that osteomalacic diseases do not occur in grazing animals, except perhaps under the exceptional conditions attending the Scottish 'croitich' [12]. This does not mean that the animals would not, in some cases, benefit by mineral supplements—only that the deficiency is rarely so pronounced as to lead to the clinically recognizable disease osteomalacia.

In Britain the farm animal most likely to develop rickets or osteomalacia is the pig sty-fed on rations from which the conventional supplement of ground limestone has been omitted. It may then arise as a combined deficiency of calcium and of vitamin D or its equivalent sunlight. This is because the pig is fed so largely on products derived from cereals which, although rich in phosphorus, are notoriously poor in calcium and contain little preformed vitamin D. Good hygienic conditions and the inclusion of minerals, usually 1 per cent. of chalk or ground limestone, 1 per cent. of bone-flour, and ½ per cent. of salt in the mixed meal, are sufficient to prevent skeletal disease in the pig. A small amount of cod-liver oil is also useful, not only as supplying additional vitamin D but as protecting against the possibility of deficiency of vitamin A [13].

Since calcium-low grain food also predominates in the rations of poultry the same precautions apply. Birds without access to calcareous grit may develop skeletal disease as an acalcicosis, or if insufficiently exposed to sunlight develop it as an avitaminosis.

Osteofibrosis.—This disease is chiefly known in equines and goats, but also occurs in the pig and the dog, and is then usually complicated with rickets and osteomalacia [1]. It has not been described in cattle or sheep and has been chiefly investigated in the horse. It sometimes goes under names such as 'equine osteomalacia' and 'osteoporosis', but these are misnomers since microscopic examination of the bones shows

it to be a distinct disease. As the name 'osteodystrophia fibrosa' or 'osteofibrosis' implies, the characteristic feature is the predominance of fibro-cellular material in the bones and not of osteoid tissue, as in osteomalacia.

The disease occurs sporadically all over the world and may appear as regional outbreaks, especially in the more tropical countries. The occasional form is often referred to as 'bran disease' or 'miller's disease' in Europe, and in England as 'big head'.

The disease develops slowly, usually runs a course of several months but may last for years in less acute form. In the early stages it often passes unrecognized, but as time goes on lameness becomes pronounced, the horse loses condition, and various skeletal deformations appear, the most characteristic feature being a thickening and softening of the jaws. The whole skeleton is weakened and may be reduced even to half its normal weight before death supervenes, but the damage may proceed to danger-point before external signs are obvious—as in recorded cases of racehorses suffering fractures during an actual race.

Over the years 1923–31, before the cause was clearly understood, it was the most serious disorder amongst the military horses in the Philippines [14]. In Britain the extreme forms are rare, but the extent to which a subdued chronic form is a contributory cause of disabling disorders of horses (lameness, exostoses, i.e. growths on bone surfaces, arthritis) requires further investigation. Whatever be the intermediary physiological mechanisms leading to osteofibrosis, the primary cause is now known to be nutritional—a large relative excess of phosphorus over calcium in the dietary. It may occur on rations in which the calcium is too low without the phosphorus being unduly high, as in the barley-feeding experiments of Niimi and Aoki in Japan [15], or it may occur in presence of adequate calcium with a large excess of phosphorus, as in the original bran-feeding experiments of Crawford in Ceylon. The later work of Kintner and Holt [14] has put the critical dietary ratio of lime to phosphoric oxide ($CaO : P_2O_5$) as between 1 : 2 and 1 : 3, but even on a ratio of 1 : 5 the disease may take over a year to become obvious.

It is now easy to understand the conditions under which the disease appears. Since in pasture grass the proportion of calcium usually exceeds that of phosphorus the disease will rarely appear in grazing horses. Since cereals and bran contain large excess of phosphorus over calcium it is likely to appear in stabled horses whenever the supply of concentrates is high in relation to roughage, and particularly when a heavy bran-ration happens to be associated with hay unusually poor in calcium. It is likely to break out as a local disease amongst military horses or in large stables in which the ration is prescribed by authority.

Bran has a wide ratio $CaO : P_2O_5$ of about 1 : 14, barley about 1 : 12, maize about 1 : 30 or wider, oats about 1 : 6; clover hay shows the narrow ratio of about 0·3 : 1, English meadow hay about 0·5 : 1, calcium-poor hay 1 : 1 or wider. If we take the ratio 1 : 2 for the complete ration as sufficiently narrow to prevent the disease, it is easy to understand why it is more likely to occur in maize-growing countries than in oat-growing countries, to be associated with areas which yield

calcium-low forage, and in Europe to acquire a name like 'miller's disease' (horses fed on excessive quantities of milling by-products).

In any case prevention, and cure in the earlier stages, is simple. It is already general practice to give a mineral supplement to pigs and poultry. A similar supplement would serve for horses; or ground limestone alone in amount calculated as sufficient to keep the whole ration to a ratio not wider than 1 : 2. In thinking in terms of ratios it should, of course, be made clear that the significance is elastic. The virtual ratio is not necessarily the real ratio of available calcium and phosphorus since certain compounds, such as the phytin of cereals (the calcium salt of inositol hexaphosphate), are very difficult to assimilate.

Magnesium

In considering magnesium the distinction already made for calcium, between food magnesium and blood magnesium, is even more striking. Several disorders are characterized by hypomagnesaemia but not by magnesium-deficiency, the best known being 'lactation tetany' or 'grass tetany' of cows.

The dietary magnesium requirements of an animal are very low and are covered by all ordinary rations, so that although magnesium-deficiency disease has been produced experimentally in rats and puppies [16] by using specially purified synthetic diets, it is very doubtful whether it will ever be found to occur naturally in farm animals. The tetany of milk-reared calves is attributed by Duncan, Huffman, and Robinson [17] to magnesium-deficiency or failure to utilize dietary magnesium, and by Sjollema [18] to protein-intoxication, but the observed hypomagnesaemia might be caused by any factor which upset the physiological mechanism controlling the level of blood magnesium.

The nature of this mechanism is unknown but, as in the case of calcium, it is presumably 'nervous endocrine'. There is, however, no reason to incriminate the parathyroids, since the hypocalcaemia which follows experimental extirpation of these glands is not accompanied by hypomagnesaemia [19]. Cannavò [20] has suggested the anterior lobe of the pituitary gland as controlling plasma magnesium, but the evidence is unsatisfactory.

When hypomagnesaemia appears suddenly it may occur alone, as in typical acute grass tetany of cows, or associated with hypocalcaemia as in 'transit tetany' of horses, or as in a mixed disorder of cows which may terminate either in coma or in convulsive seizures. A chronic hypomagnesaemia, not associated with tetany but rather with cachexia (general malnutrition), has been described by Blakemore and Stewart [21].

Lactation tetany or grass tetany.—This disease has come into prominence in England over the last decade, but most older veterinary practitioners have seen it in their youth without giving it a specific name. In Holland it is called 'grass tetany' because it occurs most typically just after the cows are turned out from stall to pasture. Sjollema [22] states that the incidence has much increased with increasing intensity of grassland management in Holland, but it seems probable that the breeding of cows for high production is the main cause of its

increased incidence throughout the world. In New Zealand it occurs in cows pastured all the year round, most commonly in spring.

In England the incidence is also seasonal and more cases occur in April, May, and June than in all the other months put together. It has, however, been occasionally reported in stalled animals in mid-winter, in almost dry cows, and at least once in a male.

The onset may be sudden, symptoms alarming, and fatal termination rapid. In its most acute forms death in convulsions may follow an hour after the first symptoms are noticed, but more usually the veterinary surgeon can reach the cow in time for successful treatment.

Hypomagnesaemia is the characteristic feature of lactation tetany and in extreme cases the plasma magnesium may vanish almost entirely. From a normal value of about 2·3 mg. p.c. the level may drop to 0·2 mg. p.c., although a common figure is 0·7 mg. p.c.; say one-third normal. Blood calcium may remain normal but usually falls appreciably.

Nervous 'irritability' is related to the level of plasma magnesium. If this falls much below normal the response to stimuli is too active and muscular tremors, spasms, and finally convulsions appear. If it is artificially raised by injection of magnesium salts nervous irritability is reduced until finally, at the very high level of about 17 mg. p.c., complete anaesthesia occurs. Treatment of lactation tetany consists in temporarily raising the level of blood magnesium by intravenous or subcutaneous injections of magnesium, so alleviating the symptoms and allowing natural recovery to take place. For this purpose magnesium sulphate is cheapest and as good as any other salt. It is non-irritant and can be injected in highly concentrated solution, usually 50 c.c. to 100 c.c. of a 20 per cent. solution for intravenous injection, or up to about 300 c.c. of a 30 per cent. solution for subcutaneous injection. Absorption from a subcutaneous injection is slower but is continuous and maintains the artificially raised blood level for a longer period of time.

With regard to the underlying cause of lactation tetany there is little precise information. Like milk fever it is almost certainly due to dysfunction of a 'nervous endocrine' regulating mechanism, but no particular gland has been successfully inæriminated. The suddenness of fall of plasma magnesium and the rapid response of acute cases to magnesium therapy suggest a physiological controlling mechanism which in susceptible animals is disorganized by a variety of 'precipitating causes'. Sudden change of environment, a railway journey, change from winter rations to rapidly growing young grass, presumably certain toxic factors, may all precipitate an attack. Probably slight attacks are more frequent than generally supposed—slight tremors followed by spontaneous adjustment of the regulating mechanism.

The chronic hypomagnesaemia recorded by Blakemore and Stewart [21] is still more obscure and does not respond to magnesium injections.

Mixed condition.—Until recently milk fever and lactation tetany have been considered independently, but Allcroft and Green [23] have plotted charts to show that a mixed condition in which both hypocalcaemia and hypomagnesaemia are pronounced is nearly as common in some districts as either alone. A plain hypocalcaemia or hypomagnesaemia can pass

over into the mixed disorder within 24 hours, and this suggests that the controlling mechanisms for plasma calcium and magnesium are interrelated.

The mixed condition may occur at any time, either as a complication to milk fever at the time of parturition, or as a complication to lactation tetany during the season of greatest incidence of that disease, or at any other time as an atypical manifestation of either disorder.

In such cases many veterinary practitioners combine calcium and magnesium therapy, or fall back on udder inflation. Fortunately the temporary rectification of either the hypocalcaemia or the hypomagnesaemia is frequently followed by spontaneous readjustment of both.

Transit tetany.—This term has been applied to a similar disease of lactating mares but which may also occur in stallions. Hypocalcaemia was demonstrated by Montgomerie, Savage, and Dodds in 1929 [7], and further associated with hypomagnesaemia by Green, Allcroft, and Montgomerie in 1934 [24]. The disorder is thus parallel to the mixed condition just described for cows although the 'precipitating cause' is different. In the equine cases the disturbance appeared in mountain ponies reared on grass, after a sixteen-hour railway journey to the Menai Bridge Fair. One of the original cases of Harvey [25] occurred after transfer from pasture to stable. Among cows the commonest precipitating cause is the reverse transfer from stall to pasture, but there are records of recovered cases of lactation tetany relapsing after transit to market.

The condition has also been described in sheep although as yet few blood studies have been made in respect of magnesium.

Iron and Copper

Iron and copper may be considered together because of their association in 'nutritional anaemia' of the domesticated animals. Anaemia, i.e. lowered haemoglobin of the blood, or reduced numbers of red corpuscles, often associated with change of size and altered haemoglobin-content of each corpuscle, may arise from various causes (e.g. worm infestation) but may be of nutritional origin. In the 'bush sickness' of cattle and sheep in the Rotorua district of New Zealand originally investigated by Aston, the 'salt sick' of Florida [26], the 'nakuruitis' of Kenya [12], and the 'pining' of Scotland [27], iron licks alone, but preferably with a trace of copper, prevent the condition, although it is by no means certain that iron-deficiency alone is the sole cause. In the case of the 'lecksucht' of cattle, sheep, and goats more recently described by Sjollema [28] in eastern Holland, an actual deficiency of copper in the vegetation seems to be incriminated and copper therapy alone is more effective than iron therapy alone.

Since the idea that copper is an essential element in nutrition is comparatively new the present views on its functions and its relation to iron may be briefly explained. Iron is an essential constituent of haemoglobin, the red oxygen-carrying matter of blood which is packed into the erythrocytes or circulating red blood corpuscles. These are formed from various precursor cells in the 'haematopoietic tissue' which fills

the cancellous spaces of the bones, and are then discharged into the blood-stream. If an experimental animal is fed upon a diet deficient in iron and copper, the erythrocytes are not formed in sufficient numbers and not always properly packed with haemoglobin, so that a 'nutritional anaemia' results. If a purified iron salt is now added to the diet, iron is stored in the liver but very little formation of haemoglobin occurs in the red marrow unless traces of copper are also added. If copper is then substituted for the iron the liver reserves are mobilized and haemoglobin is formed. Addition of copper alone to the deficient diet brings about an increase in the number of reticulocytes (reticulated erythrocytes) in the blood but the total haemoglobin formation is small.

Addition of iron following the copper now produces a second 'reticulocyte response', but this time with normal haemoglobin formation. It would thus appear that copper assists in the mobilization of iron in the body and in the formation of haemoglobin. The reason why the significance of copper has been overlooked in the past is that the quantities required are so small that the traces present in most foods are sufficient. It is therefore of special interest that Sjollema should attribute a naturally occurring disease of domesticated animals to copper-deficiency in certain pastures.

Pig anaemia.—The case of pig anaemia is different from the anaemia of 'bush sickness' and 'pining', since it is not the food of the adult which is incriminated but the composition of the sow's milk in relation to the requirements of the litter. From time immemorial mother's milk has been regarded as the perfect food for the infants of all species, but apparently the intervention of man in selectively breeding pigs for phenomenal production has created a situation in which the demands of the fast-growing pigling for rapid haemoglobin formation have outrun the capacity of the mother to supply sufficient iron through the milk. The fact that some piglings in a litter suffer more than others, and that some litters suffer more than others under apparently the same conditions, suggests a genetic factor—perhaps operating as a capacity to make the best use of the small amount of iron available.

The anaemic condition is characteristic of sty piglings and rarely occurs in pigs farrowed out of doors and reared on grass runs, where a little extra iron is incidentally obtained by early rooting and swallowing of soil particles. It is easily prevented under sty conditions by supplying a little iron direct to the piglings—not to the mother, who is already well supplied from her own food but is unable to increase the amount in her milk.

Prevention can sometimes be accomplished by throwing freshly cut grass sods, preferably impregnated with iron, into the sty, but is more certainly accomplished with very little trouble by painting the udders of the sows with a suitable iron mixture at least once a day. A common mixture is $3\frac{1}{4}$ oz. of iron sulphate and $\frac{3}{4}$ oz. of copper sulphate dissolved in a pint of water and then mixed with a pint of treacle or syrup to make the solution sticky and more palatable.

Pig anaemia is much commoner than many breeders suppose. For

instance, Doyle, Mathews, and Whiting [29] give certain records from the United States in which 89 per cent. of the deaths up to 8 weeks after farrowing were attributed to anaemia. Aderson [30] and Olofsson [31] stress the economic importance of pig anaemia in northern Europe. Foot [32] refers to the death of 10 per cent. of the pigs born at the National Institute for Dairy Research at Reading over the years 1931–3 from anaemia during the first 8 weeks of life, and to successful subsequent prevention by administration of iron.

In general the piglings are born with normal haemoglobin, which ordinarily falls somewhat over the first 10 days and then rises again if the iron supply is adequate, but which continues to fall if it is not, so leading to a pathological anaemia. The pigling may succumb, or recover as soon as it begins to take sufficient food independently of the mother's milk. When death supervenes it is not always as a simple result of the anaemia, and when recovery occurs it is not always perfect. The piglings suffer a set-back and in their weakened state are more liable to contract secondary disorders to which the healthy pigling is more resistant.

Iodine

Iodine-deficiency in acute form is comparatively rare in farm animals except in certain well-defined areas of the world, but may occur sporadically even in Britain. Rationed animals may sometimes receive sub-optimal quantities of iodine and benefit by iodized salt. On the other hand, indiscriminate use of iodine supplements in excessive amounts may have adverse effects [33].

One of the best-known cases of acute deficiency occurring on a large scale was recorded from certain American states in which 'foetal athyrosis' [34] or 'hairless pig malady' occasioned considerable losses prior to 1917. Piglings were still-born, or born hairless and died shortly after birth, even when the mothers were apparently healthy. The trouble was dissipated by including traces of potassium iodide in the rations of the breeding sows. Sporadic cases of foetal athyrosis have been observed in England on very badly constructed rations.

Goitre in sheep was at one time prevalent in Michigan and prevented by adoption of salt containing traces of iodine. Goitre in sheep, cattle, and goats has been reported from Canada, Switzerland, New Zealand, and elsewhere, and correlated with iodine-deficiency in drinking water and pasture. An 'Iodine Survey of New Zealand Livestock' has been made by Mason [35], who places the critical value for iodine in sheep's thyroid at 0·03 per cent. on the fresh gland; below this the gland increases in size as the iodine-content diminishes, sometimes reaching a weight of fifty times the normal. Salt licks containing 3 oz. of potassium iodide per cwt. of salt have successfully prevented further trouble. Hopkirk, Dayus, *et al.* [36] reported an outbreak of congenital goitre in lambs, all of which were born weak with enlarged thyroids, whilst many were hairless or deformed. Sporadic cases of a similar nature, involving a small proportion of lambs in a flock, have been reported from Somerset and Dorset in areas known to be border-line in respect of iodine, and although the problem of iodine-deficiency is not acute in

British farm practice the question of 'iodine intake below the optimum' merits further investigation.

Iodine-deficiency is usually reflected as 'thyroid hyperplasia': as soon as the store of iodine in the gland falls below a certain level the thyroid tissue increases in an endeavour to produce a sufficiency of its iodine-containing hormone to meet physiological requirements. But direct iodine-deficiency is not the only cause of thyroid hyperplasia, and any factor which reduces absorption of iodine or increases the utilization of the thyroid hormone may also cause goitre. In the human subject sporadic goitre can occur in localities rich in iodine. Spence [37] gives an account of the production of goitre in rabbits by cabbage-feeding, and shows that it is dependent upon a positive goitrogenic substance destroyed by air-drying and not dependent only on the iodine-content of the cabbage. He also discusses the presence in certain plants of anti-goitrogenic substances other than iodine. Continuous administration of certain organic cyanides may be goitrogenic by depressing tissue-oxidation and so producing a compensatory reaction on the part of the thyroid gland, the iodine-containing hormone of which raises the metabolic rate.

In theory, simple goitre is due to iodine-deficiency; in practice it is due to a combination of factors which bring out the insufficiency.

Fluorine

The element fluorine is mentioned not because any case of fluorine-deficiency has ever been suspected, but because 'fluorosis' due to excessive fluoride-content of certain drinking waters, or use of mineral supplements rich in fluorine for correcting phosphorus-deficiency, has been recorded. The disease 'darmous' affecting all domesticated animals, but particularly sheep, in the rock-phosphate areas of North Africa is discussed by Velu [38, 39] as a spontaneous fluorosis.

Hupka and Gotze [40] reported cases of fluoride poisoning in cattle. Du Toit, Malan, Groenewald, and de Kock [41] record an experimental study of the effects of fluoride on pregnant heifers. Loss of weight and swellings on the long bones of the extremities were the characteristic features. One heifer died before calving and the other had to be destroyed. In the more chronic fluorosis of 'darmous' in Morocco the most characteristic feature is dystrophy of all the permanent teeth, which takes the form of erosions in the enamel; the teeth wear down quickly and the animal is unable to feed.

Sodium, Potassium, and Chlorine

It is not proposed to discuss the physiological functions of these elements, and since no naturally occurring diseases have yet been proved to be due to deficiency or imbalance between them little need be said. 'Salt hunger', manifested as a craving for salt, is well known in areas in which the vegetation is low in sodium or chlorine, and a salt lick is commonly supplied to farm animals, even if only as a condiment. Much has been written on the importance of the ratio of sodium to

potassium in a ration and some of the earlier views on alkali-deficiency in relation to the lecksucht of East Prussia have been discussed by Green [42], but earlier theories have not stood the test of time. Orr includes a discussion of these elements in his 'Minerals in Pastures' [12].

In natural pastures potassium greatly exceeds sodium and no deficiency of potassium has ever been suspected. Sodium and chlorine may sometimes be very low but the extraordinary tenacity with which sodium chloride is retained in the body in times of shortage is an automatic safeguard against deficiency. Although the kidneys can readily excrete large excess, the urine becomes almost chloride-free when the diet is rendered salt-free, so that it is not an easy matter to produce a 'sodium chloride deficiency disease' by dietary régime alone. If, however, a secretion such as the gastric juice is simultaneously drained off by operative procedure the animal is unable to protect itself against loss, and symptoms of chloride-deficiency rapidly appear. The external secretion milk is rich in chloride, so that salt may become a limiting factor in milk production—the defence of the animal being protective cessation of lactation. Of recent experiments the data of du Toit, Malan, and Groenewald [43] are of considerable interest. They fed heifers on a basal ration low in minerals containing 6·7 gm. chlorine (Cl), 5·7 gm. soda (Na_2O), and 29·3 gm. potash (K_2O) for the whole period of gestation and early months of lactation. No adverse effects were noted until lactation began and drained off about two-thirds of the sodium and chlorine. Milk yield rapidly fell off, from 24 lb. to 2 lb. within 3 months. These figures give some indication of minimum requirements for maintenance and suggest that the sodium- and chlorine-contents of pastures would have to be astonishingly small before adverse effects, other than protective cessation of lactation, would appear. The authors suggest that about 14 gm. Cl, 15 gm. Na_2O, and 38 gm. K_2O are sufficient in the daily ration of a cow producing 2 gallons of milk. On this basis the sodium-content of certain sodium-low pastures in various parts of the world would be insufficient for adequate milk production without a salt lick, but not necessarily inadequate for survival of the animal itself.

Summary

A brief survey of the dietary significance of phosphorus, calcium, magnesium, iron, copper, iodine, fluorine, chlorine, sodium, and potassium is given with reference to diseased conditions in the animal, such as osteoporosis, osteomalacia, rickets, osteofibrosis, nutritional anaemias, and hypomineralaemias.

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THE NYASALAND TOBACCO INDUSTRY

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NYASALAND is a strip of country 500 miles long in tropical Africa. It stretches from latitude 9° S. to 17° S. and for most of its length it lies between Lake Nyasa and Northern Rhodesia. The southern portion is enveloped by Portuguese East Africa and in the extreme north it adjoins Tanganyika. It has no seaboard and communicates with the outside world through the Portuguese port of Beira with which it is connected by rail. A railway bridge across the Zambezi River was completed this year, and it is now possible to carry produce from the shores of Lake Nyasa to Beira without transhipment.

Blantyre and Limbe are the largest towns. Limbe is the tobacco-marketing centre and here the factory of the Imperial Tobacco Company is situated. It is 345 miles by rail from Beira, and 275 miles by road from Quilimane.

The native population exceeds one and a half million and consists of a number of tribes of which the most numerous are the Angoni and Achipeta in the north, and the Yao and Nyanja in the south. Much of the labour on the tobacco and tea estates is supplied by the Anguru, a race that lives mainly in the adjoining Portuguese territory.

On the whole the soils are very fertile. Most of the country is between 2,500 and 4,000 ft. above sea-level. The rainy season lasts from November to April, and the rainfall ranges between 25 and 45 in., except in the tea districts, where it reaches 55 to 70 in. A little effort during the rainy season provides the native with sufficient foodstuffs—maize, beans, cassava, millet—for his needs throughout the year. A hut tax of 6*s*. per annum is levied and this makes it necessary for him to work on the European tobacco or tea estates or to grow produce for sale. The principal native crops grown for this purpose are tobacco, cotton, and maize.

Introduction of the tobacco plant.—It is generally agreed that the tobacco plant is not indigenous to Africa, but came from America by way of Europe through the agency of early Portuguese explorers or traders. It was unknown to Europeans before the first voyage of Christopher Columbus to America in 1492. Seeds were carried to Spain and Portugal between 1556 and 1560, and tobacco was grown in the Royal Gardens at Lisbon in 1558. The Portuguese explorer, Vasco da Gama, rounded the Cape of Good Hope in 1495, and traders followed who established settlements along the east coast and up the Zambezi River. There seems little doubt that the tobacco plant was introduced through these early settlements and that it was soon carried into the interior by the natives.

In De Flacourt's *Histoire de Madagascar* (1661) reference is made to the cultivation of tobacco by the natives of that island. When Dr. Livingstone explored the Zambezi Valley and the country round Lake Nyasa (1851–73) he found that tobacco was grown everywhere. His companions on one expedition, Sir John Kirk and Mr. J. C. Meller, sent

specimens of the plant to Kew, where it was classified as *Nicotiana tabacum*, the species native to America.

In his book *British Central Africa* (1889), Sir H. H. Johnston, who was H.M. Commissioner and Consul-General to the territory now called Nyasaland, wrote as follows:

> Of his cultivated plants, maize, manioc, sweet potato, tobacco, tomato . . . reached him from America. Although these things are now spread right across Africa in their cultivation, they are natives of America and were introduced from two to three centuries ago by the Portuguese.

The Nyasaland tribes have no common name for *Nicotiana tabacum*, the pink-flowered species of tobacco. It is known as 'fodia' by the Nyanja, Chipeta, Chisena; 'hoona' by the Chihenga; 'sona' by the Yao. This diversity of names may indicate the antiquity of the original importation. The original strain may still be grown for local use in remote districts. In the developed districts any pink-flowered variety is referred to as 'fodia'.

There is also a yellow-flowered species grown by the natives for snuff-making called 'labu' (Nyanja and Yao). Seed which was sent home by the writer was identified at the Royal Gardens, Kew, as *Nicotiana rustica* var. *asiatica* Schrank. This species is cultivated also in North Africa and Syria, and was probably introduced into Central Africa by Arab traders.

The natives of this part of Africa have grown tobacco for about 300 years.

Development of the industry.—Nyasaland was declared a British Protectorate in 1889 and tobacco first figured among the exports in 1893. Production steadily increased and the progress of the industry may be judged from the following table of exports of tobacco of all types:

	lb.		*lb.*
1911 . . .	2,146,615	1926 . . .	9,142,437
1913 . . .	3,763,014	1928 . . .	11,632,497
1916 . . .	4,304,124	1930 . . .	12,934,914
1918 . . .	5,805,396	1931 . . .	10,690,581
1920 . . .	4,963,130	1932 . . .	15,082,035
1922 . . .	6,330,808	1933 . . .	10,394,498
1924 . . .	7,044,175	1934 . . .	12,544,126

This development was due to the European settlers who had taken up land in the district roughly 40 miles north and south of Blantyre. The labour force required was considerable, and whilst a nucleus was employed throughout the year, the majority was made up of labourers engaged for the season of five or six months. The operations of sowing, transplanting, cultivation, topping, and curing were controlled by the planter through 'capitaos' (overseers) selected from the labour force for their intelligence and reliability. Many of these men became able growers, and learnt the art of fire-curing from the settlers. They had long been accustomed to curing their own tobacco and drying it on the roofs of their huts, but the method of using sheds and smoke from smouldering logs was new to them.

Since 1920 great changes have come about owing to various factors, such as the changes in market requirements, the fall in commodity prices, opening of new areas to production and native developments. The cigarette has become increasingly popular, and for this purpose a bright type of cured leaf is required which is the natural product of light sandy soils. Climatic conditions greatly influence the yields per acre and thus affect the cost of production. Soil and climatic factors are becoming more appreciated as they decide what type of leaf can be produced economically in a given area and the tendency is for the centres of production to move to the appropriate areas. The fall in prices has hastened this movement. More attention is being paid to quality so as better to supply the requirements of the market and to meet the competition of other producing countries.

The most pronounced increase has been in the native production of dark fired tobacco, which is used for pipe mixtures. Air-curing and fire-curing are simple operations compared with the flue-curing of bright cigarette leaf and most of the dark fired tobacco is now a native product. All the flue-cured tobacco is produced by Europeans.

Dark fired tobacco.—Strains of tobacco have been developed by breeding and selection to meet particular requirements, and the so-called Western types have been so obtained for air- and fire-curing. A strain which is popularly called 'Western' has been standardized by years of local selection, and Nyasaland fire-cured tobacco is almost exclusively of this strain. It probably has no exact counterpart to-day in the United States, its country of origin, and is now worthy of its official designation 'Western Dark Nyasa'. It shows good resistance to diseases, and stands up particularly well to local conditions.

Dark fired tobacco is produced in most parts of the country. A few pioneers opened estates in districts 200 miles north of the older settlements and produced leaf of excellent quality. The natives around took up tobacco culture extensively and at the present time most of the dark fired tobacco is produced in the Northern Province. The Government has done much to improve the quality of the product by the establishment of a Native Tobacco Board and Experimental Stations. The Board issues permits to native growers for the use of crown land, and supplies the seed at a small charge. It maintains tobacco instructors in recognized districts for the guidance and control of the native farmers in the matters of cultivation, topping, priming, curing, and grading. Buying stations or markets have been established at suitable centres and only such grades as are approved by official inspectors are allowed to enter the markets, thereby maintaining a high quality.

Tobacco appeals to the natives as a useful cash crop. Its expansion is limited by the requirements of a market which other parts of the Empire are also desirous of supplying.

Dark fired tobacco is produced on private estates also, by native tenants, and this meets with keen competition from that grown on crown land. The development of this class of tobacco can be judged from the following table, which shows the quantities of dark fired tobacco sold and the numbers of natives engaged in its production:

The crown-land grower has had considerable advantages in the past. His interest in a piece of land ceased after the crop was harvested. If fertility appeared to be falling off, he moved to a new spot and, following old native practice, burned off the timber as the easiest means of clearing it. This gave him a large application of lime and potash gratis and freed the soil from pests for a season. The maintenance of fertility did not worry him. On an estate, only too frequently is a bad patch explained by the remark 'an old native garden'. He uses no artificial fertilizer, but even sells his goat and cow manure to the nearest European planter.

Year	*Quantity sold*	*Number of growers*
	lb.	
1924	1,176,000	..
1925	2,636,480	..
1926	4,531,396	..
1927	7,804,757	66,321
1928	5,407,944	34,761
1929	8,694,253	47,578
1930	9,481,732	48,419
1931	7,883,139	51,903
1932	13,225,490	53,044
1933	9,131,911	56,026
1934	11,320,717	60,247

The European has invested his capital in an estate whose fertility he endeavours to maintain. He drains and terraces his fields to check erosion, rotates with legumes and maize, uses artificial fertilizer to improve the yield and quality, takes measures to control diseases and pests, and practises afforestation. There is no local market for his alternative crops, nor can they be exported profitably at the present time.

The differences of outlook and of land tenure between the white settler and the native have weighed greatly in favour of the latter, and if he were left to pursue the old native practices unchecked, the good tobacco-lands would quickly deteriorate and a valuable asset would be lost after a brief period of prosperity. The Native Tobacco Board has already done good work in connexion with growing and marketing the crop, but the fundamental principles of agriculture urgently call for attention so as to maintain the great asset of the country.

Flue-cured tobacco.—This class of leaf is produced exclusively by Europeans. The exports in recent years have been:

	lb.
1930	2,866,569
1931	2,590,253
1932	2,260,500
1933	1,644,479
1934	1,933,259

There has been a marked reduction of acreage and fall in production in the last few years. The types of leaf most in demand are semi-brights and semi-darks of good body, suitable for use in pipe tobaccos. The varieties Gold Leaf, Warne, Cash, Yellow Prior yield a good proportion of such grades when grown under favourable conditions.

The growth and curing qualities of the tobacco plant are very sensitive to weather conditions. Thus the saleable leaf from a given field may vary between 200 and 600 lb. per acre according to the season. Low temperatures, excessive rainfall, lack of sunshine, prolonged misty weather, wind, hail are all inimical. Temperature and rainfall control the rate and amount of growth. Misty weather favours the development of leaf diseases, which are sometimes responsible for great losses, particularly of the flue-curing varieties.

Some of the older estates were situated near the escarpments and in the mist zone. In such situations the odds are against the tobacco-planter, and this is where the main reductions of acreage have taken place. Outside this zone the grower has a better chance of planting with success. Land of low fertility is essential for the production of good-quality flue-cured tobacco; this has not been sufficiently appreciated in the past.

Successful tobacco culture demands a combination of appropriate climatic and soil conditions. A large surplus of land is necessary to enable fields to be rested to regenerate the conditions which are found in newly-opened land. Lastly, alternative crops are very desirable both for rotation purposes and to carry the planter over seasons which are adverse to tobacco.

Air-cured and sun-cured tobacco.—The development of these types are indicated by the following export figures:

	lb.
1930	38,329
1931	147,455
1932	166,443
1933	824,396
1934	866,713

The varieties 'Western' and 'Greenwood' are mainly grown, as well as a certain amount of Burley. Suitable areas are more restricted owing to the peculiar climatic conditions necessary for the curing process when the leaf is very subject to injury by rain. The soil should be of similar type to that on which fire-cured tobacco is grown.

Acknowledgements

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ERRATA

Vol. III, July 1935, p. 278, line 11 from top, *in lieu of* Dolba Grange *read* Dolga Grange; p. 284, line 21 from top, *in lieu of* 0·75 *read* 0·73; p. 288, line 19 from top, *in lieu of* sown *read* sowing-date.

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